THE UNIVERSITY OF ALBERTA

A COMPARISON OF THE WORK CAPACITY OF THE URBAN AND RURAL SECONDARY SCHOOL POPULATIONS IN THE PROVINCE OF ALBERTA AS MEASURED BY THE ASTRAND SUBMAXIMAL BICYCLE ERGOMETER TEST

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Comparison Of The Work Capacity Of The Rural And Urban Secondary School Populations In The Province Of Alberta As Measured By The Astrand Submaximal Bicycle Ergometer Test", submitted by Howard James Green in partial fulfilment of the requirements for the Degree of Master of Science.

ABSTRACT

The purpose of this study was to investigate the work capacity of the urban and rural secondary school students in the province of Alberta.

The sample, representing areas chosen on geographical, social and economic criteria and deemed to be representative of the secondary school population of Alberta, was composed of approximately three percent of forty-five city, town and village schools. School enrolment lists enabled those tested from each school to be randomly selected. In all, the results of 809 urban and 108 rural students were accepted for analysis.

The test selected was the Astrand submaximal test of work capacity in which the maximal oxygen intake of a subject was predicted through the use of a nomogram.

Tests were carried out to determine if the difference between the rural and urban mean values was statistically significant at the .05 level of confidence.

The subsidiary problems were designed to investigate selected variables related to the validation of the Astrand submaximal test. For this aspect of the study, twenty-nine male and thirty-five female subjects, the majority of whom had been previously tested as part of the main problem, underwent the Astrand actual and the Astrand predicted test of maximal oxygen uptake. Data for height, weight, and knee extensor strength were also collected.

Correlation coefficients to determine the relationship between work performed and strength with the actual and predicted values were

computed and tested for significance. The data for heart rate and oxygen consumption was analyzed to determine the trend of these values with increasing work load.

Within the limitations of this study, it was concluded that there was a statistically significant difference between the urban and rural males and between the urban and rural females in the province of Alberta when the measure of work capacity was expressed in litres per minute. The mean values were: for the male and female rural sample, 3.20 and 2.16, and for the male and female urban sample, 2.91 and 2.03. No such significance was found when these values were expressed in millilitres per kilogram of body weight.

When these mean values were expressed in litres per minute and the sample subdivided into age groups, a statistically significant difference between the male urban and rural groups was shown only for the 17 year and 18-20 year groups. A significant difference between the means was found only for the male 17 year-old group when the values were expressed in millilitres per kilogram of body weight.

For the subsidiary problem, correlation coefficients of 0.94, 0.97, and 0.95 were found between heart rate and work load, oxygen consumption and work load and heart rate and oxygen consumption for ten male subjects.

For fourteen female subjects the correlation between oxygen consumption and work load was 0.91.

When the male values for heart rate were plotted against work load only a significant linear trend was found. The curve fitted to oxygen consumption and work load showed a statistically significant linear and

quadratic trend for both the males and the females.

A statistically significant relationship was found between measured maximal oxygen uptake and work performed for both the males ($r = 0.69$) and the females ($r = 0.68$). The relationship between work performed and the average knee extensor strength was significantly different from zero for only the male subjects ($r = 0.51$).

The criterion established by Astrand to indicate the measured maximal oxygen uptake on the actual test was found to be generally acceptable for the subjects tested in this study.

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STATEMENT OF THE PROBLEM

Introduction. Physical fitness has become an important concern in both Canada and the United States of America. In the United States of America the physical fitness movement received increased emphasis when President Kennedy re-established the Conference of Youth Fitness only one month after his election to the presidency of the United States (3). The recommendations of this conference on Youth Fitness included the establishment of objective, valid tests of physical achievement to determine pupil status, measure progress and motivate pupils to achieve increasingly higher levels of physical fitness.

In Canada, under the direction of Prime Minister Diefenbaker, the Government of Canada made law the Fitness and Amateur Sport Act on the 29th of September, 1961 (22). This Act is designed to encourage, promote and develop fitness and amateur sport in Canada. More specifically the Act (22) states that it shall:

> (a) provide bursaries or fellowships to assist in the training of the necessary personnel;
>
> (b) undertake or assist in research or surveys in respect of fitness . . . ;
>
> (c) arrange for national and regional conferences designed to promote and further the objectives of this Act;
>
> (d) provide for the recognition of achievement in respect of fitness . . . ;
>
> (e) prepare and distribute information relating to fitness;
>
> (f) co-ordinate federal activities related to the encouragement, promotion and development of fitness . . . ;

(g) undertake such other projects or programmes including the provision of services and facilities or the provision of assistance thereof, in respect of fitness . . . ;

These provisions suggest, in part, that a nationally recognized test of physical fitness is needed whereby an individual might examine his present capacity and measure any future progress. The ultimate development would be the establishment of norms for the entire population. Such an accomplishment would give the individual a more basic knoledge of his present status and would enable him to compare his results with others in this country and in other countries using a similar test. Further, such results could be used in industry, in military training, in the field of sports and in a clinical evaluation of physical fitness (11).

Two major problems become readily apparent and each must be solved if the concept of widespread physical fitness evaluation is to be realized. One problem is that our researchers have not provided us with practical and proven tests of physical fitness whereby extensive samples of the population can be investigated. The other major problem is related to the preliminary investigation that must first be conducted before a task of this magnitude can be undertaken. Problems of sampling, of reliability and validity of method and of test administration are only a few of the difficulties that must be refined before objective measures can be obtained on the various diverse aspects of a national population.

At present there is no test generally recognized as the best test of physical fitness. The reasons are derived in part, from a failure of the authorities to agree on a uniform definition of physical fitness and in part, on a lack of specific tests designed to give a valid measure of the various components involved. Consolazio, _et al_ (30) state

that the quantitative measurement of physical fitness is one of the most complex and controversial problems in applied physiology. Linde (62) suggests that the large number of general methods used to study exercise fitness indicates that no single test is completely satisfactory.

One major aspect of physical fitness is certainly cardiorespiratory endurance or work capacity and several investigators (12,19,34,53,62) contend that the best estimate of physical fitness is related to this concept or the ability of the individual to perform heavy, prolonged work. Astrand (12) feels that during heavy prolonged work, the individual's performance capacity depends largely on his ability to take up, transport and deliver oxygen to the working muscles. Rodahl, et al (10) believe that maximal oxygen uptake or aerobic capacity is the best measure of a person's physical fitness, providing the definition of physical fitness is restricted to the capacity of the individual for prolonged heavy work (70). Newton (67) further contends that the maximal oxygen intake is the best single physiological indicator of the capacity of man for sustaining hard work. A number of investigators (1,5,21,34,44,53,69,82,88) are in direct agreement that work capacity is limited mainly by oxygen uptake.

Adams, et al (1) believe that a work capacity test has a number of advantages over other methods in that it is objective, reproducible and easily administered with few trained individuals. The main objection to a work capacity test is that it requires a maximal effort by those involved and therefore can only be used on a certain aspect of the population. If a test of work capacity is to be accepted on a widespread basis, to be used by all, then a prediction of the maximal work capacity will be necessary. Linde (62) considers that a submaximal test would be more advantageous in that all groups could be compared, younger

and older individuals could perform the test and it would have extensive clincial use. Cumming and Cumming (32) conclude that a predicted test would eliminate the variation found in maximal tests due to psycholigical factors such as motivation.

Generally the recommended approach to measuring work capacity on a widespread basis would appear to be to use tests of a submaximal nature. One such submaximal test that has received considerable attention has been developed by Astrand (14), a Swedish physiologist. The test purports to be able to predict the aerobic capacity of an individual from the pulse rate response in a steady state to graded work loads of submaximal intensities.

It is essential that, if such a test is to receive endorsement, the objectivity, reliability and validity of the test be determined in the situation in which it would receive application. By subjecting the test to typical experimental environments information could be accumulated in which the influence of various factors on the predictive power of the test could be investigated. Among the variables that merit consideration are the pre exercise heart rate (78), the physical condition of the subject (72), the linearity of heart rate, oxygen consumption and work load (16), and the muscular strength and endurance of the subject (49).

If the study were designed to encompass a large population, considerably more information could be derived that might be vital to national interests. The results could be used to determine if the test were capable of detecting differences due to sex, age and physical activity and to determine the magnitude of these differences if, in fact, they did exist. A basis would then be established from which future studies of this nature could follow.

<u>The Problem.</u>

The purpose of this study is to compare the work capacity, as measured by the Astrand submaximal test, of a sample of the rural and urban population as found in the secondary schools of Alberta.

The null hypothesis asserts that there is no difference between the work capacities of the urban and rural students studied. The alternate hypothesis asserts that there is a difference between these groups.

<u>Subsidiary Problems.</u>

The subsidiary problems are to investigate, using a determined maximal oxygen uptake on the bicycle ergometer:

(1) The relationship between oxygen consumption, heart rate, and work load.

(2) The relationship between static strength of the knee extensor muscles, total work performed and oxygen consumption.

(3) The effect of continued work on the oxygen intake of a subject after the accepted criteria designating maximal oxygen intake has been reached, i.e., two consecutive readings having a difference of no more than 0.080 litres.

<u>Limitations of The Study.</u> The conclusions regarding the main problem of this study will be limited by;

(1) The use of a nomogram which enables an individual's aerobic capacity to be predicted. Specifically, the study will be limited by the validity of the nomogram as an accurate predictor of maximal oxygen consumption and the reliability of the nomogram, which was established in Sweden using subjects 18 to 30 years of age.

(2) The validity of the stratified random sample as representative

of the Alberta secondary school population and as representative of the rural and urban secondary school populations.

(3) The magnitude of experimental error resulting from the measurement of heart rate by palpation of the carotid artery.

For the subsidiary problems this study will be limited by;

(1) Only students attending the secondary schools of Edmonton, Alberta will be used as subjects.

(2) The methods and instruments used to collect the data.

(3) The statistical procedures used to analyze the data.

(4) Only the influence of the strength of the knee extensor muscles in relation to oxygen consumption and work performed will be investigated.

Definition of Terms

Maximal Oxygen Intake. Maximal oxygen intake has been described by Hill (34) as a point which is an apparent "steady state" during exercise in which the oxygen intake is constant. The maximal oxygen intake is a measure of the maximal capacity of the cardiovascular-respiratory system to take up, transport and deliver oxygen to the working tissues and for these tissues to use the oxygen. In this test, the state is said to have occurred when a measurement of maximal oxygen consumption does not exceed the preceding measurement by 80 ml.//min.

Steady State. During a steady state, the oxygen intake is equal to the oxygen expenditure. For the purpose of the Astrand test (14), the criterion designating a steady state is when the heart rate between two successive readings, taken at one minute intervals, does not differ by more than ± 5 beats per minute.

Work Capacity. For practical use work capacity is defined as the maximum work capacity that is consistent with a steady state.

Kilopond Meter (KPM). One kilopond meter is the force acting on the mass of one kilogram (kg) at the normal acceleration of gravity.

Stratified Random Sample. This sample is identical with that used by the Alberta Government in their labor force studies in so far as the locations are concerned (86). The size of the sample is greater, representing three percent of the secondary school population. The sample itself includes the public and separate schools of 45 cities, towns and villages located in the Province of Alberta.

Urban Areas. Urban areas as used by the 1961 Census (27) definition specifies that all cities, towns and villages of 1,000 and over, whether incorporated or unincorporated be classified as urban, as well as the urbanized fringe of all such centres if the agglomeration was 10,000 or more.

Rural Area. The rural areas include all the remaining locations in the sample.

Secondary School Population. The secondary school population refers to all those presently enrolled in Grades 10,11,12 in the Province of Alberta.

CHAPTER II

REVIEW OF THE LITERATURE

Essentially this review will be concerned with the meaning of physical work capacity, the use of maximal oxygen intake as an index of physical work capacity and finally with an examination of the various criteria that pertain to the use of a submaximal test to predict maximal oxygen uptake. Specifically, the Astrand-Ryhming nomogram as a valid method of predicting maximal oxygen uptake will be investigated.

Physical Work Capacity and Maximal Oxygen Uptake. It is not postulated that physical work capacity is synonomous with physical fitness. It is generally recognized that work capacity measures only one aspect of fitness, namely the ability of the individual to perform prolonged, heavy work (30). It is this ability that has led some investigators to consider work capacity as a measure of physical fitness (65,82). Fowler and Gardiner (46) believe that physical fitness includes a combination of medical, functional and motor performance fitness. Functional or organic fitness consists of the capacity to perform and recover from maximal and submaximal exercise.

Consolazio, et al (30) consider that of the components for evaluating physical fitness, endurance is one of the most important, since it is required for performing heavy work over extended periods of time. A good test of physical fitness should conform to the following criteria (30:341):

1. It must place the cardiovascular system under considerable stress by involving large groups of muscles.

2. It should be so intense that at least one-third of all the test subjects will stop from exhaustion within five minutes, but the work intensity should not be so high as to make motivation play a dominant part.

3. It should not demand any unusual type of skill for successful performance.

4. The work load must be carefully determined, reproducible, and fairly easy so that the mechanical efficiency is kept relatively constant.

Adams, et al (1:250) point out that among the many ways of assessing physical fitness, the work capacity test has a number of advantages in that it is objective, reproducible and easily administered with few trained individuals and the results permit comparison with various groups of healthy and diseased individuals.

Astrand (12:307) defines fitness as " . . . the ability of the organism to maintain the various internal equilibria as closely as possible to the resting state during strenuous exertion and to restore promptly after exercise any equilibria which have been disturbed." Darling (34) believes that any of a variety of measures made during heavy exertion or during recovery may serve as an index of fitness, provided they show a wide enough spread between fit and unfit individuals and provided they are not easily influenced by extraneous influences. The most important component of fitness is taken to be the capacity of the individual for prolonged, heavy work (12,19,53).

Work capacity has been defined as the maximum work intensity that is consistent with a steady state (30). "During heavy, prolonged physical work, the individual's performance capacity depends largely on his ability to take up, transport and deliver oxygen to the working muscle" (71:277). Wahlund (88) concludes that in tests which require a large number of muscles, maximum oxygen consumption should be regarded as a reliable measure of maximum work capacity. He believes that there is probably a continual decrease in physical working capacity from the most well-trained athlete to the heart patient. Newton (67) agress in the value of maximal oxygen

intake in sustaining hard work and he concludes that it is the most objective measure by which one gains insight into the physical fitness of an individual as reflected by his cardiovascular system. Astrand (11) argues that our present knowledge of the limiting factors in working capacity is incomplete. To Astrand working capacity is a synthesis of aerobic and anerobic capacity, mechanical efficiency and physical condition. In later studies (8,12,13,18) he frequently equates work capacity with maximal oxygen uptake.

Rodahl et al, (70:164) report that:

> the reloading of the contractile mechanism demands energy, which in turn is liberated either from the restricted stores in the muscles themselves or from food stuffs and oxygen transported to the muscles from the blood stream. The rate of work that can be maintained over a longer period will, therefore mainly depend on the transportation capacity of the cardio-respiratory system. For assessment of the capacity for muscular performance, measurements of muscular strength and of maximal oxygen uptakes during work, therefore, must be of the greatest importance.

Cumming and Cumming (32) contend that the object of any work test is to increase the oxygen requirement of the subject. Therefore the two most reliable measurements of cardio-respiratory function are those of oxygen consumption and cardiac output. Taylor (79) emphasizes that the capacity to maintain a high oxygen consumption over a period of time demonstrates a large degree of cardio-vascular and respiratory fitness. In testing circulatory and respiratory fitness, a type of work must be chosen that engages large groups of muscles, the working intensity must be high, the duration of the work must be long enough to permit the adjustment of circulation and ventilation to the exercise, and the determinations have to be done particularly during the latter phases of adaptation (11). Linde (62:656) hypothesizes that a superior state of physical

fitness is illustrated by a smaller increase in heart rate for any given energy output and less rise in respiratory rate.

<u>The Astrand Bicycle Ergometer Test</u>. The Astrand test (14) is considered to be a measure of physical work capacity, provided the definition of physical work capacity is restricted to maximal oxygen uptake. Astrand's submaximal test consists of pedalling a bicycle ergometer at a set work load for 5-6 minutes until the heart rate reaches a previously defined steady state. Through the application of a nomogram developed by Astrand and Ryhming (16) in 1954, the prediction of the aerobic capacity of healthy individuals is possible.

Astrand (6:45) outlined three prerequisites for using this nomogram:

(1) that pulse rate during submaximal work increases approximately rectilinearly with oxygen intake.

(2) that submaximal pulse rates not lower than 125 beats per minute are used for the prediction.

(3) that the pulse rate of the subject can reach a maximal value of 195 beats (standard deviation ± 10) when cycling or walking.

A criticism preventing the general acceptance of the nomogram is that it was based only on the results of 27 male and 31 female, well-trained subjects 18-30 years old (16). It was found that a prediction could be made with a standard deviation of less than ± 10 percent on these same subjects.

<u>Validity and Reliability</u>. A review of the literature reveals that there are relatively few studies on the validity and reliability of the nomogram as such. Astrand (6) indicates that when applying the nomogram on data for submaximal oxygen uptake and heart rate, the standard deviation

for the measured maximal oxygen uptake is less than ± 10 percent for well-trained younger persons but about ± 15 percent for the whole group.

The nomogram is applicable to three basic tests, cycle, step, and walking or running on the treadmill. It has been found (6) that the predicted value for maximal oxygen uptake in cycling is more accurate than walking, if the submaximal oxygen uptake is not measured. There seems to be a similar accuracy for the step test and the cycling test when they are compared using young, well-trained adults.

"It should be strongly emphasized here that this method of measuring only the submaximal oxygen uptake or work load and heart rate will always be only an aid for a rough prediction of the aerobic work capacity" (6:59). If a greater accuracy is demanded then a direct measurement of the actual capacity will be needed.

Astrand and Ryhming (16) established the validity of their nomogram by comparing the calculated and estimated values of oxygen uptake of the subjects studied. The submaximal test was a cycle test with a work load of 900 kgm per minute for women and 1200 kgm per minute for men. Analysis of the values gives a mean difference of .023 ± .059 litres of oxygen per minute for men and .010 ± .051 litres of oxygen per minute for women between the determined and calculated maximal oxygen intakes. For 2/3 of the cases the standard deviation was less than 6.7 percent for men and 9.7 percent for women. With a lower rate of work, 900 kgm per minute for males and 600 kgm per minute for females, the respective standard deviations were 14.4 and 10.4 percent. A further test of the validity was established when 18 well-trained, male subjects, 18 and 19 years of age, showed a mean difference between predicted and actual values of .006 ± .066 litres per minute on the step test and .020 ± .058 litres per minute on the treadmill

test. The standard deviation was less than 7 percent in each case. For 31 female and 28 male subjects, 20 to 30 years of age, the maximum oxygen intake was calculated from the heart rate and oxygen intake when doing a cycle test and also when doing a step test. The two values of the calculated maximum oxygen uptakes were compared and the mean difference was .003 ± .052 litres per minute for the women and .025 ± .057 litres per minute for the men. The standard deviations were 9.5 and 7.3 percent respectively.

Borg and Dahlstrom (24), using a bicycle ergometer test with successively increased power levels and a work duration of six minutes at each level, studied different measurements related to work capacity on 78, 20 year old male forst workers who were enlisted in the army. The intra-test consistency was assessed by correlating the heart rates with each other after 2, 4 and 6 minute work periods. The highest intra-test correlations were found between the pulse rates from the fourth to the sixth minute at a work load of 900 kpm per minute. On the first test this reliability coefficient value was 0.97, and on the re-test, 0.98. The correlation coefficient values for 600 kpm per minute and at the same times are 0.90 and 0.94 respectively. The correlations for pulse rates at the second and fourth minute are somewhat lower.

The test, re-test correlation coefficients for heart rates averaged between 0.50 and 0.60 for 600 kpm per minute power levels and between 0.60 and 0.70 for the 900 kpm per minute levels. These low test, re-test correlations may be explained by the fact that the first test was administered in the summer of 1957 and the re-test in the spring of 1958.

Borg and Dahlstrom's criteria for validation of the Astrand test of work capacity can also be subjected to serious criticism. The evaluation of the validity of the Astrand test resulted from a 20 mile skiing race, timed between the two experimental tests and using 42 subjects. It is not surprising that the highest correlations (0.38 and 0.45) were obtained between the second work capacity test and the skiing race.

The correlation between the Astrand values within the tests are 0.83 and 0.79. These correlation coefficients must be considered high as they are based, to a certain extent, on the assessment of two power levels. The test, re-test correlations for the Astrand values at the 1200 kpm per minute work level on both tests was 0.71 and the averages for both power levels was 0.67. These low correlations might be explained by the difference in fitness levels that could very easily have occurred during the several months that elapsed between the two tests.

Hettinger, et al (53) compared the predicted values of maximal oxygen intake determined from the nomogram and corrected for age to the measured intake values as determined on a bicycle ergometer. In the 28 policemen studied, age range 20 to 30 years, they found that the mean predicted maximum was 2.62 litres per minute and the mean measured value was 2.38 litres per minute. This difference was significant at the 5 percent level of confidence. These values are considerably lower than the 4.11 litres per minute that Astrand and Ryhming (16) found in a group of Swedish men of the same age. Two possibilities are suggested to explain the difference. The Swedish subjects were well-trained individuals as compared with the relatively untrained policemen and it is possible that the measured maximal oxygen uptakes were not attained by the subjects in this study. In an attempt to check the reliability of the measured

maximum oxygen uptake nine policemen between the ages of 23 and 48 years were randomly selected and then their maximum uptake was again measured. The procedure used parallelled the first test with the exception that blood lactate levels were used as the criterion indicating maximal uptake. When these results were compared with the predicted values there was a difference of only 4.8 percent. The predicted mean value was 2.65 litres per minute as compared to 2.54 litres per minute for the measured (70:285).

In another group of nine physically well trained men between the ages of 56 and 68 years, Astrand, Astrand and Rodahl (9) calculated a mean value of 2.27 litres per minute as contrasted to the measured value of 2.24 litres per minute. This difference is 3 percent. In a younger group of untrained men, varying in age from 23 to 48 years, the difference between the two values was only about 1 percent. The respective values for predicted and measured intakes were 2.72 and 2.76 litres per minute (70:285).

In the original study by Hettinger, et al (53) a comparison was made between the measured maximal oxygen uptakes and the results of certain other selected tests on which each subject was also tested. The results show highly significant correlations between the maximal oxygen uptake and the Harvard step test and the maximal oxygen uptake and the modified step test.

In 1964, de Vries and Klafs (36), using a total of sixteen subjects, conducted a study in which they investigated the validity of several submaximal work capacity tests by comparing the predicted values with an actual maximal oxygen consumption value determined on a bicycle ergometer. Of the submaximal tests used, the Sjöstrand test, the Harvard Step test and the Astrand-Ryhming test gave significant correlation between the

predicted and the actual values. For the Sjöstrand test, the values expressed in kilopond metres per minute per kilogram of body weight, the correlation was 0.877 and for the Astrand-Ryhming test, expressed in litres per minute, the correlation was 0.736.

Recently, Rowell, et al (72) studied the predictability of maximal oxygen intake in normal male subjects 18-24 years of age. These investigators contended that if various factors such as emotional state of the subject, degree of physical conditioning, total circulating hemoglobin, the degree of hydration of the subject and alterations of ambient temperature act to change only the slope of the linear relationship between heart rate and oxygen uptake then estimates of cardiovascular performance can still be made. Specifically, this study attempted to analyze the influence of the effects of physical conditioning on the prediction of this capacity. One group, composed of seven sedentary subjects, was tested on both the actual and predicted test then underwent a strenuous physical conditioning program for 2½ to 3 months. It was found that the predicted test underestimated the maximal oxygen uptake value by 27 $\pm$ 7 percent before training and by 14 $\pm$ 7 percent after training. In another group, composed of ten endurance athletes of high national intercollegiate calibre, the underestimation from the predicted test was reduced to 5.6 $\pm$ 4 percent.

It was concluded that there is a marked trend towards improved accuracy of prediction with increased degree of physical training.

<u>Work Capacity and Sex</u>. It is an established fact that the physical working capacity is less for females than for males (11). Based on this fundamental fact, when using the nomogram constructed by Astrand and Ryhming, it is necessary to calculate different values for maximal oxygen intake.

TABLE I

NOMOGRAM CORRECTION FACTORS RECOMMENDED FOR MEN AND WOMEN

AGE	FACTOR FOR MEN	FACTOR FOR WOMEN
20	1.06	1.00
30	0.93	0.90
40	0.82	0.82
50	0.74	0.75
60	0.67	0.69
70	0.61	0.64

Source: Astrand (6:53)

Astrand (11), in a comparison of the maximal oxygen intakes of males and females between the ages of 14 and 18 years, expressed in per kilogram body weight, found a range of 52.5 to 63.7 for the males and a range of 42.8 to 49.3 for the females. Further investigation revealed that the values for female groups, age 4 to 11 years, was lower by 13 to 17 per cent than for the boys of the same age group. For an age range of 14 to 25 years this difference increased by 26 to 29 per cent. The smallest difference was observed between the 12 and 13 year old groups and this difference represented 6 per cent. Astrand believes that the oxygen intake is fairly linear up to the age of 13 years, but after that the oxygen intakes increase more rapidly for men. In another investigation (11), involving 35 subjects in a maximal cycling test, the mean value of heart rate was 191 $\pm$ 1.9 beats per minute which resulted in a maximum oxygen uptake of 4.03 $\pm$ 0.07 litres per minute. Using a similar testing procedure the determinations for 32 females showed a mean heart

rate value of 194 $\pm$ 1.6 and an oxygen uptake value of 2.76 $\pm$ 0.05 litres per minute. For 42 male subjects and 44 women subjects, Astrand (12) found values of 4.11 litres per minute and 2.90 litres per minute for each sex. This represents a difference of 29 percent. For 18 female and 17 male students working on a bicyle ergometer maximal test, the values were 36.0 and 51.0 ml. per kg. for the females and males respectively. This difference is highly significant at $p < .001$ (12). Astrand (11) is of the opinion that the gradually increasing difference between males and females is due to an increase in fatty tissue in women as a result of sexual maturity.

During submaximal work Astrand (11) found that the oxygen consumption increased linearly with work intensity for both males and females and that they generally fitted the same curve. At a work load of 900 kpm. the values given for the oxygen intake for females was 2.06 litres per minute as compared to 2.09 litres per minute for the males. As part of the same study, but using work loads of 900, 1200 and 1500 kgm. per minute for the males and 600 and 900 kgm. per minute for the females, Astrand again determined average values for oxygen uptake. On 21 well-trained male subjects between the ages of 20 and 33 years he found values corresponding to work intensities of 900, 1200 and 1500 kgm. of 2.09, 2.67 and 3.33 litres per minute respectively. For the females, aged between 20 and 25 years, the values for the 600 and 900 kgm. work loads were 1.48 and 2.06 litres per minute respectively. The average values of the oxygen intake at the different intensities were found to follow an almost straight line regardless of sex. The average heart rates for the female subjects were only 8 to 10 beats higher than for the males when comparison was

made for a certain percentage of the respective aerobic capacities.

Astrand, et al (15) determined the oxygen uptake, cardiac output, stroke volume and oxygen content of arterial blood in 11 women and 12 men 20 to 31 years of age, at rest and in condition of maximal and submaximal work. In preliminary studies, the maximal oxygen uptake for the female subjects was 2.61 litres per minute with a maximal heart rate of 189. In additional experiments with simultaneous measurements of cardiac output, the values were 2.60 and 194 respectively. For the male subjects the preliminary studies revealed a maximal oxygen uptake of 4.12 litres per minute with a heart rate of 185 beats per minute. When cardiac output was measured the values obtained increased to 4.05 and 186 respectively. In the two sets of experiments, both carried out on a bicycle ergometer, the amount of work preceding the maximal exercise was different, but the same oxygen uptake and heart rate were roughly attained.

In a study by Adams, et al (2) the method of determining work capacity as developed by Sjöstrand (77) was used on 120 male and 103 female subjects, between the ages of 6 and 14 years. The results of their study show differences between the sexes even at the earlier ages and as growth proceeds the sex differences become much greater so that by the age of 14 years there is almost no overlap of the observations in boys and girls. In a similar study (1), done in Sweden, it was also found that the boys had significantly different work capacities than the girls for the same body size, age and heart volume.

Astrand (13) concluded from a study of the maximum work capacity of the two sexes aged 4 to 30 years, that the maximum oxygen intake is 30 per cent lower for females than for males. This value is reduced to

20 per cent if the oxygen intake is expressed in per kg. body weight. He found no significant sex differences before puberty.

Bengtsson (21), in a study of 38 subjects, evenly divided as to sex and ranging in age from 15 to 40, determined that the maximal oxygen intake was approximately 30 per cent higher in adult males than in adult females. In other age groups studied, of the age range between 5 and 14 years, no significant differences whatsoever were obtained.

Cumming and Cumming (32), in a study using a different concept of working capacity (that work load performed at a minute pulse rate of 170), found a consistently greater working capacity for Winnipeg school boys, age 6 - 16 years as compared with a similar group of girls. He found the maximum working capacity for 11 and 12 year old boys and girls to be 170 and 386 kgm. per minute respectively.

Metheny, _et al_ (64) substantiated the differences found by many other investigators in maximal oxygen uptake for the two sexes. The subjects used were physical education students between the ages of 19 and 27.

Rodahl, _et al_ (70) in an investigation of the maximum oxygen uptake of 601 randomly selected Philadelphia students, ages 8 - 18, found little differences in the relative capacities of each sex up to the ages 10 to 12 but after this there was a marked difference.

Linde (62) points out that sex differences in maximal oxygen uptake are evident from early childhood and increase in magnitude with growth and development. "At all ages, females need a higher pulse rate to transport the same amount of oxygen or to expend the same amount of energy" (19:656).

Sexton, (76) in detailing a longitudinal study carried out on a bicycle ergometer at the Child Research Council, University of Colorado School of Medicine, cites that clear-cut and consistent sex differences were found when the test values were calculated into percentile scores. The minimal differences occur briefly at age 8 and the maximal differences at age 15. The experimental evidence presented consistently confirms significant differences between the sexes. These differences on the average tend to remain minimal up to puberty for both sexes, then marked superiority for maximal oxygen intake is demonstrated by the males.

Work Capacity and Age.

Fairly definite conclusions have been drawn on work performance as related to age since Robinson's study (69) on ninety-one subjects in 1938. Robinson studied the interrelations of age, basal heart rate and oxygen uptake in moderate and exhaustive work on a treadmill. In the normal subjects investigated, varying in age from 6 to 91 years, he was able to conclude that the capacity for oxygen uptake in severe work is related to age and that the mechanisms for supplying and utilizing oxygen in exhausting work are only about fifty per cent as effective in a man of 75 as in a boy of 17 years. He found a highest mean value of 3.71 litres per minute in boys of average age 17.4 years. In other groups, divided as to age, he discovered a gradual decline in both directions from this peak to 0.98 litres per minute in the group with average age 6.0 years to 1.71 in the group with average age of 75.0 years. This is in general agreement with the heart rate values which also showed a gradual decline from a maximum of 198 in small boys to 158 beats per minute in the three men averaging 75 years of age.

Recently Adams, et al (2), using the procedure designed by Sjöstrand (77) to measure physical work capacity, did a study on 243 male and female students, age 6 to 14 years, enrolled in the elementary and junior high schools of California. They found that within this age range the working capacity increased for both males and females. In a similar study (1) done in Sweden and using city and country school subjects, ages 10, 11 and 12 years, the results also illustrated that work capacity increases with age. For the ages 10, 11 and 12 years, the mean values were 420, 423 and 460 kgm. per minute respectively. A correlation coefficient of 0.38 was found between work capacity and age on 58 of the city school boys.

Bengtsson (21) examined the work capacities, as adjudged from a submaximal exercise on a bicycle ergometer, of 39 girls and 37 boys between the ages of 5 and 14 years. For these ages a steady rise in work capacity at a given heart rate was observed. The 5 and 6 year old children showed a work capacity of only 37 per cent of the 13 or 14 year olds while the 10 to 12 year old group showed 44 per cent of that achieved by adults. Cumming and Cumming (32), using a similar submaximal test on a bicycle ergometer, found that there was also a gradual rise in work capacity with increasing age. This conclusion was obtained from the results of 200 Winnipeg school children ranging in age from 6 to 16 years. The determinations of an additional study (33) compare favourably with those previously mentioned.

Astrand (11) has done considerable work on age and sex differences as related to work capacity. From the results of maximal oxygen uptake tests administered to 112 females and 115 males, aged 4 to 33 years, on

both the treadmill and bicycle ergometer, he concluded that the increase in oxygen uptake is fairly linear up to the age of 13 years but after that the oxygen intake increases more rapidly for men. He found that the greatest individual variations were between the ages of 12 to 15 years. The results of the measured values for males 4 to 6 years are 1.01 litres per minute; ages 12 to 13 years, 2.46 litres per minute; ages 14 to 15 years, 3.53 litres per minute; and 4.11 litres per minute for adults. The females in this experiment showed a gradual increase from 0.88 litres per minute for the youngest to 2.90 litres per minute for the adults.

Astrand (11) has demonstrated that girls show a decrease in aerobic capacity per kg. body weight from the age of about ten years as contrasted to no decrease in males for the same age. Up to the age of 25 years, oxygen intakes ranged from 0.47 to 53 mm. per kg. body weight per minute but after that age there was a consistent decrease in aerobic capacity (6).

More recently, Astrand (14) has published a new booklet on work tests with the bicycle ergometer and the following factors were given to correct the predicted maximal oxygen value for age or for when the maximal heart rate is known.

TABLE II

FACTOR TO BE USED FOR CORRECTION OF PREDICTED MAXIMAL OXYGEN UPTAKE

AGE	FACTOR	MAXIMAL HEART RATE	FACTOR
15	1.10	210	1.12
25	1.00	200	1.00
35	0.87	190	0.93
40	0.83	180	0.83
45	0.78	170	0.75
50	0.75	160	0.69
55	0.71	150	0.64
60	0.68		
65	0.65		

Source: Astrand (14:28)

Rodahl, et al (70) found that the maximal oxygen uptake of 126 Philadelphia school subjects showed a progressive increase from ages 10 to 22 years for both sexes. However, wide differences existed between the results obtained on trained and untrained individuals.

In a study by Astrand (6), 44 female subjects were divided into age groups of 20 to 39, 40 to 49 and 50 to 65 years and their oxygen intake was measured during exhausting work on a bicycle ergometer. A review of the results revealed that the 20 to 29 year old group had the greatest maximal oxygen uptake of 2.23 litres per minute. The oldest age group, 50 to 65 years, showed a mean value of 17 percent less. This decrease is 29 percent if the oxygen intakes are expressed as per kilogram body weight. Additional research (8), using the same procedures to measure physical working capacity, showed that in 81 male workers, all over 50 years of age, the maximal oxygen consumption decreased with age. The values for oxygen uptake in litres per minute and heart rate in beats per minute for each class were: 50 to 54 years, 2.55 litres and 161 beats; 55 to 59 years, 2.43 litres and 158 beats; 60 to 64 years, 2.14 litres and 158 beats. These maximal values are 62, 59 and 52 percent of the values found by Astrand for younger subjects. Astrand concluded that the original nomogram cannot be used effectively for older subjects especially if the subjects cannot reach a maximal heart rate of 195 beats per minute during work.

The realization that actual differences do exist in working capacities between different age groups has led Astrand to initiate more studies on age differences and working capacities. One study (66) was designed to investigate the validity of the nomogram for age groups other than those

involved in the construction of the nomogram. The subjects used were housewives, age 20 to 65 years, draymen, age 50 to 64 years, young males, age 27 to 45 years and elderly men, age 56 to 68 years. The results revealed that a significant difference exists between the measured and predicted values in the maximal oxygen intakes. This difference necessitated a correction factor for certain age groups if the nomogram were to become valid.

In the construction of this correction factor the difference between predicted and measured maximal oxygen uptake values in percentage of the measured value was calculated for each subject. The correlation coefficient for the individual variations in percent between calculated and measured oxygen uptake was, for the females, 0.722 ($p < .001$) and for the males, 0.778 ($p < .001$). Regression lines were established and a factor for each age above 25 was calculated with which the estimated maximal oxygen uptake should be multiplied to agree with the measured value. The factors begin with a value of 1 for age 25 years and terminate with a factor of 0.65 for age 65 years. These correction factors can be applied equally well to both males and females. When these predicted values for oxygen uptake were corrected, the average differences between estimated and measured values for each group expressed in litres per minute were: housewives, 0.014 $\pm$ 0.042; draymen, -0.036 $\pm$ .042; young males, - 0.109 $\pm$ 0.071 and elderly men, -0.029 $\pm$ 0.090. Astrand also observed in this study that the accuracy is somewhat higher if higher work loads are used.

Durnin, et al (42), as part of a study on work capacity, contrasted the results obtained on two groups of young and elderly men on heavy treadmill exercise. He found a progressive falling off in circulatory

and pulmonary function in the elderly men as the severity of the work increased.

Mitchell, et al (65), in order to determine maximal oxygen intakes on 65 normal subjects, used an exhausting treadmill test. The values for each group of subjects, divided into age ranges of 20 to 29, 30 to 39, 40 to 49 and over 50 years were 3.37, 3.04, 2.94 and 2.13 litres per minute respectively. These differences enabled the investigators to state that if a submaximal test is to be used for functional evaluation then these age trends must be taken into consideration.

This review indicates that there is a progressive increase in maximal oxygen uptake up to the age of 20 years. From age 20 to 30 years there is a gradual decrease in maximal capacity and this decrease becomes more pronounced after age 30 (70).

Relationship Between Pulse Rate, Work Load and Oxygen Consumption.

The validity of the nomogram as an objective estimate of maximal oxygen capacity depends upon the existence of a linear relationship between oxygen uptake and heart rate. The existence of such a relationship has been a widely investigated and controversial aspect of the Astrand test. Astrand and Ryhming (16) indicate that this relationship is only accurate between heart rates of 125 and 170 beats per minute and that heart rates within this range only should be used for prediction purposes.

Rodahl, et al (71:280) state that:

> In any given individual there is a linear relationship between oxygen uptake and heart rate during submaximal work. The slope of this line changes with the state of physical training or physical fitness; a fit person is able to transport the same amount of oxygen at a lower heart rate than an unfit person. This relationship in general is independent of sex and age, although females require higher heart rates to transport the same amount of oxygen than males.

Taylor (84:149) is of the opinion that there are a number of situations where a singular measurement of a submaximal pulse will not allow prediction of maximal oxygen uptake. Karpovich (58) explains that it is impossible to prepare a table of the relations between oxygen uptake and heart rate for all people, and that individual tables must be constructed for each experimental subject. Taylor, et al (85) also contend that the slope of the curve is different for each individual. They list temperature, meals, time of day, fatigue and mechanical efficiency as factors which could cause an overestimation of work capacity. They conclude that it is generally agreed that during submaximal work on a bicycle ergometer, oxygen consumption can be predicted with a reasonable degree of accuracy if the weight of the subject is known and the rate of work is known and maintained constant.

Erickson, et al (44), Boothby (23), Krogh and Lindhard (60) and Schneider (73) have all found an approximate rectilinear increase between oxygen consumption and heart rate. Krogh and Lindhard warn that each individual shows a different rate of increase which may or may not be the same as that of another person. Schneider (73), in his investigation, used 6 males and subjected them to increasing work loads of 2000, 6000, 8000 and 10,000 foot lbs. per minute, and the results showed that with moderate work loads the addition of equal increments to the work load resulted in an approximately linear increase in oxygen consumption. With heavier work loads this function tended not to maintain this increase. On five of the six subjects studied a similar relationship was observed for pulse frequency and work load.

Lundgren (63), investigating the connection between pulse rate and

oxygen consumption, found a reasonably good relationship between the two variables when different types of lumber work were compared with a bicycle ergometer test.

Wahlund (88) and Sjöstrand (77) have found that in any normal individual there is a linear relationship between the amount of work performed and the oxygen consumption, cardiac output and heart rate.

Wahlund (88) investigated several physiological variables on a progressive work capacity test using a bicycle ergometer. The subjects used were divided into three groups: workmen who had complained of respiratory troubles, athletes and military recruits. In general, he found a linear relationship between heart rate and oxygen uptake in all groups for heart rates between 155 and 175 beats per minute. Roughly speaking, no differences exist in this relationship when work load is used instead of oxygen consumption. It was possible to estimate oxygen consumption from work load within a range of ± 8 percent in two-thirds of the cases.

Astrand and Hart (4) and Asmussen, et al (5) believe that there is a linear correlation between heart rate during steady state exercise and oxygen consumption. Asmussen's data indicate that the oxygen increase is approximately linear up to a heart rate of 170 and 180 beats per minute, where it begins to level off. The time at which this levelling off occurs is dependent on the degree of training in that it is lower in untrained than in trained subjects.

Asmussen, et al (5) also found a rectilinear increase in heart rate and oxygen uptake when the subjects walked on a treadmill or drove a tricycle with the arms.

The dependence of the nomogram on this linear relationship has led

Astrand and Ryhming to undertake several investigations into this area. In one study, composed of female subjects, varying in age from 20 to 65 years, Astrand (11) found an approximately linear relationship between heart rate and oxygen uptake in all age groups. There was also a similar relationship between work load and oxygen uptake at submaximal loads. However, the investigator emphasizes, the method of measuring only the submaximal oxygen uptake will serve only as a guide for rough prediction of aerobic work capacity. On younger subjects, age 4 to 33 years, it has been shown that the pulse frequency in a steady state increased almost rectilinearly with increasing work load. This was valid for adults for a heart rate increase from about 125 to 170 beats per minute. Older men, 56 to 68 years, also exhibited this rectilinear property showing a similar increase in both heart rate and oxygen uptake with increasing work loads (9).

In another study, Astrand and Astrand (8) found that the precise regulation of heart rate with increasing work load was little affected when subjects were highly motivated.

In the construction of the original nomogram (16), it was observed that the oxygen uptake of the well trained subjects could be estimated from work load within a range of ± 8 percent in two-thirds of the cases. However, when a greater number of subjects was used, 50 male and 62 female, this range decreased to ± 6 percent in two-thirds of the subjects.

Bengtsson (21) found a strictly linear relationship between heart rate and exercise intensity with subjects under 14 years during performance on a bicycle ergometer. The correlation coefficient between the two variables for both sexes was 0.94.

In subjects 10 and 11 years of age, Cumming and Danzinger (33)

found the same relationship which was valid for pulse rates as high as 210 beats per minute.

Taylor (79) limited a study to two subjects in which 24 individual determinations were conducted on each of them over a period of two months. Correlation coefficients of 0.97 and 0.96 were found between work load and heart rate in both subjects. In an extension of this same experiment, he found correlation coefficients between these two variables on three other subjects to be 0.90, 0.69 and 0.94. In 50 percent of all the cases studied there was no deviation in the linear increase of oxygen intake at exhaustion and in the remaining cases the value accelerated more than fell off. The investigator concluded that heart rate, total ventilation, oxygen consumption and respiratory quotient all increase with work load in an approximately linear fashion and the ultimate level reached is subjected to individual variation.

Wyndham, et al (90) have criticized the nomogram constructed by Astrand and Ryhming on the grounds that the oxygen uptake-pulse rate relationship does not exist over the full range of values for heart rate. This criticism was based on the results of 4 subjects trained to cycle at 70 rpm. for 30 minutes and then to exhaustion at various levels at work. It was found that the plotted mean values of heart rate and oxygen intake appeared to have a linear function at low work rates but at high work rates it became an exponential function. The oxygen uptake and heart rate curve demonstrated linearity up to an near maximum value of heart rate and then there appeared to be a marked curvilinear relationship leading to higher oxygen intake values than would normally be obtained. These researchers also found that the oxygen intake values tended to increase

after an initial levelling off had occurred.

Astrand (6) contends that the criticism presented by Wyndham, et al is not applicable to the prediction of aerobic capacity. "It is not the premise that the heart rate is a rectilinear function of oxygen uptake throughout the range of values" (6:60). The nomogram was constructed empirically where the predicted values of oxygen uptake were compared with the determined values. Astrand warns that the altitude at which this study was carried out could have resulted in hypoxia, thereby introducing a resultant decrease in heart during submaximal work.

Rowell, et al (72:925), in a study designed to investigate the limitations of submaximal tests, revealed how the nomogram of Astrand-Ryhming was originally developed;

> If the VO_2 to pulse rate slope is originated at 60 beats/min. and zero VO_2 and then extrapolated through a single value for submaximal VO_2 and pulse rate to 195 beats/min., the VO_2 at the latter point corresponds exactly to that read from the nomogram as predicted max. VO_2. The pulse rate at 50% of this predicted max. VO_2 will always be 128 beats/min. In this manner the nomogram of Astrand and Ryhming may be reconstructed.

Accuracy of prediction for all groups used in this study varied with approximation of pulse rate to 128 beats per minute at 50 per cent of maximal oxygen uptake.

These investigators have suggested that the discrepancy observed by Wyndham, et al is due, not to the asymptotic approach of oxygen uptake and pulse rate to maximal values, but to the fact that the subjects used in the study were only able to achieve maximal pulse rates of 178 beats per minute. Since the nomogram requires extrapolation of pulse rates to 195 beats per minute and since the pulse rates shown by Wyndham, et al at 50 per cent of maximal oxygen uptake were less than 128 beats per minute,

the result should have been to overestimate the true maximal oxygen intake value.

The Bicycle Ergometer. The use of the bicycle ergometer for determinations of maximal oxygen intake has been both criticized by some and encouraged by others. A review of the literature reveals that two of the basic criticisms against the use of the bicycle are that the maximal oxygen capacity cannot be obtained because of local muscular fatigue and that there is a changing mechanical efficiency for different sexes, ages and work loads. With due regard to these criticisms, the bicycle has many advantages that favour it as an ideal instrument in work capacity tests.

Wahlund (88), in a survey of maximal tests, lists several values of the bicycle ergometer. Among these he includes the practicability of the bicycle for laboratory use, that the work can be exactly reproduced, that a large number of muscles are involved in cycling, that oxygen consumption is directly related to work loads, that the mechanical efficiency of various individuals shows a comparatively slight difference, that various determinations are easily made during work, that work intensity can be adjusted so that the subject is not overloaded and that it is possible to make a direct comparison between different subjects at different work loads, as there are few extra movements not taking part in the production of work output. He concludes (88:19) that ". . . on the assumption that the subject to be tested has had some opportunity to practice cycling, this type of work may be preferred to any other."

Dill (39) points out that the treadmill is to be preferred to the ergometer in this country because the experienced rider has an advantage

over the non-rider. However, he considers this advantage to be of minor importance.

It is generally agreed (11,30,44,62) that the bicycle ergometer meets the criteria of a good physical fitness testing instrument as outlined by Rodahl, <u>et al</u> (70). It places the cardiovascular system under considerable stress by involving large groups of muscles, it does not demand an unusual type of skill for successful performance and the work load can be carefully determined, is reproducible and fairly easy so that the mechanical efficiency is kept fairly constant.

Several studies have been done comparing the maximal oxygen uptake values of individuals on each of the bicycle ergometer, the treadmill and the step test (11,12,18). Astrand (11) found that the type of work, whether running or cycling, had no definite influence on the maximal values of heart rate or oxygen uptake. From a study, involving 40 males, he found mean maximal values for heart rate and oxygen uptake during running to be 189 ± 1.6 beats per minute and 4.04 litres per minute. For 35 subjects on a cycling test these values were 191 ± 1.9 beats per minute and 4.03 ± 0.07 litres per minute. For females the values for running were 198 ± 1.6 beats per minute and 2.89 ± 0.04 litres per minute and for cycling 194 ± 1.6 beats per minute and 2.76 ± 0.05 litres per minute. Astrand hypothesized that the higher values reported during skiing ". . . are probably due to the fact that the effort during skiing is spread to a large number of powerful muscles and that the muscles will be working under relatively favourable conditions, due to alternation of work and relative rest during the glide" (11:115).

When the original nomogram was constructed in 1954 (12), the step test, the treadmill run and cycling test were all employed in maximal determinations. The cycling test values, of 4.11 and 4.15 litres, determined at work loads of 900 and 1200 kgm. per minute, were both higher than the step test value of 4.03 litres per minute.

Astrand (6) states that when using the nomogram all three of these tests can be used, however the predicted value for maximal oxygen uptake during cycling is more accurate than walking if the submaximal oxygen uptake is not measured. For cycling and the step test there seems to be a similar accuracy for the well-trained individuals who acted as subjects.

Asmussen, et al (5) discovered that in normal male subjects, between the ages of 20 to 29 years, there was a lower oxygen uptake for a given heart rate when the subjects walked on a treadmill as compared to pedalling a tricycle for leg work. They further devised a formula from which maximum oxygen intake could be determined from measurements made during submaximal work using Robinson's and Astrand's data.

Astrand and Saltin (17) did an extensive study on the maximal oxygen intakes and heart rate in various types of muscular activity. Maximal work was performed by the legs on a bicycle ergometer, by the arms plus the legs using two bicycles, by arm work on a bicycle ergometer, by running on a treadmill, by skiing and by swimming. The results of their comparison showed a value of 4.23 litres for normal cycling in a sitting position and 4.24 litres for cycling with the arms and the legs when using two bicycles. For running, the maximal value was 4.69 litres as compared with 4.47 litres for the same subjects examined while cycling. For skiing the value was 4.48 litres as compared with 4.36 litres for the same

subjects in cycling. These investigators call attention to the fact that these results do not conform to observations from other experiments where significantly greater values were found for running than cycling.

In 7 male subjects, ranging in age from 19 to 70 years, Newton (67) used four methods of measuring oxygen capacity. These were the Balke test, the Cureton all-out run, the treadmill test with speed and grade adjusted to the capacity of the individual and the bicycle ergometer test. The highest maximal values were obtained with either the Balke test or the standard treadmill run. The values obtained from the bicycle ergometer and the Cureton test were consistently lower than those obtained with the other tests except in the case of highly trained subjects.

Glassford (49) designed a study to permit a comparison of the values obtained on four maximal oxygen consumption tests. In a group of 24 healthy male subjects, age range 17-33 years, he found that the treadmill tests employed and the Astrand-Ryhming predicted test yielded significantly larger ($p=.05$) maximal oxygen consumption values than did the modified Astrand Bicycle Ergometer test.

Both Glassford (49) and Baycroft (20) list as a possible reason for this significant difference, the fact that the subjects complained both of insufficient strength to pedal at the work loads required for a maximal effort and extreme fatigue of the knee extensor muscles. In their opinion research should be undertaken to determine the relationship between leg strength and maximal oxygen consumption as determined on the bicycle ergometer.

Rodahl, et al (70) compared maximal values obtained on the modified step test and the cycle test of 126 Philadelphia school children. These

experimenters found a statistically significant correlation ($p < .05$) between maximal oxygen uptakes in both the tests administered.

"If the oxygen intake is regarded as an important factor for determining fitness for endurance work, the mechanical efficiency, technique or skill, must be regarded as another decisive factor" (12:315). The importance of a constant mechanical efficiency for all subjects has been often expressed in the literature. If the element of skill determines the level and extent of performance then this will have a definite effect upon the maximal oxygen uptake for each individual.

Taylor, et al (85) state that ample evidence suggests that repeated tests on a bicycle ergometer can result in a substantial change in mechanical efficiency.

Rodahl and Horvath (71) are of the opinion that the results of previous experiments have established that the mechanical efficiency of work on a bicycle ergometer is about the same for trained and untrained individuals as well as for Swedish and American subjects.

The mechancial efficiency has been defined as the total work performed times 100 divided by the difference between the total energy used and the basal energy exchange (11). Mechanical efficiency calculations were performed on 21 male and 31 female subjects at various work intensities on the bicycle ergometer (11). It was found that the values differed by less than 0.1 per cent from the means of all the calculations. For the males the efficiency varied between 23.3 and 23.7 per cent while the values for the females ranged between 22.5 and 23.1 per cent. For the subjects used, age range 4 to 33 years, no significant variation in mechancial efficiency was shown with age.

In a study designed to determine the mechanical efficiency of an older age group, Astrand (6) revealed several significant findings. This investigator found that in the male subjects there was a significantly lower mechanical efficiency at 300 and 600 kpm. per minute for the oldest group than for the youngest group. In the female subjects this lower efficiency was observed at work loads of 300 and 450 kpm. per minute but at 600 kpm. per minute there was no difference between the groups of relatively young housewives and physically well-trained students. "The difference in mechancial efficiency between the youngest and the oldest female and male groups at 300 kpm. per minute would correspond to a deviation from the standard value of about .08 litres per minute or about 30 to 40 per cent . . . "(6:32).

Astrand, et al (8) have also studied the mechanical efficiency of workers 50 to 64 years old on a bicycle ergometer. The calculated efficiency for subjects attempting the maximal test averaged between 22 and 23 per cent.

Mechanical efficiency of cycling depends upon the intensity and rate of movement, but the optimum is stated quite differently by different investigators. Astrand (11) feels that this is due to the fact that the determinations were not done in a steady state.

In a cycle test on subjects ranging in age from 5 to 14 years and at a work rate of 45 to 60 rpm. depending on the preference of the subjects, Bengtsson (21) found that mechanical efficiency, based on 26 determinations, varied between 18 and 24 per cent.

In an attempt to determine the metabolic efficiency of work on a bicycle, 9 experienced cyclists were subjected to increased work loads at

a constant pedal speed (52). It was found that the efficiency, defined as the ratio of the external work accomplished over the net metabolic cost of the work decreases from 0.212 for light work to 0.193 for heavier work. This represents a highly significant reduction of 9 per cent.

Rodahl, et al (70), using a random method for the selection of the subjects studied, administered a submaximal test to students on a bicycle ergometer. They found that within an age range of 8 to 18 years, the mechanical efficiency was 23 per cent for the males and 21 per cent for the females. The mechanical efficiency for 14 year old Stockholm boys was 23.1 per cent at a work load of 600 kpm. and 23.9 per cent for Philadelphia boys of similar age and under a similar work load.

Taylor, et al (81) used a pedal frequency of 54 to 65 rpm. at a constant work load to determine the mechanical efficiency of 19 boys, aged 7 to 15 years. The values obtained for net efficiency of the age groups studied were: 6 to 8 years, 18.4 ± 0.4 per cent; 9-11 years, 22.8 ± 0.3 per cent; 12 to 15 years, 17.9 ± 0.2 per cent. When the cost of sitting was deducted from the determinations of efficiency, these values averaged in order, 24.6, 30.8 and 23.7 per cent. These investigators consider that efficiency varies with speed, the external work performed, the training of the subjects, the duration of the work performed, diet and the base lines used in determining net efficiency.

Garry and Wishart (48), in an experiment with two subjects, found that optimum gross efficiencies occurred at a speed of 52 pedal revolutions per minute. Dickinson (37), in constrast, investigating with speeds from 8 to 60 pedal revolutions, obtained the highest efficiency at 33 rpm. Briggs (25), in a study on Scottish soldiers, found 56 rpm. to be the most

comfortable speed.

These results agreed, in general, with the 50 pedal revolutions per minute that is used on the Astrand submaximal test.

Work Capacity Tests in North America. Few extensive studies on physical work capacity have been conducted in North America. One notable exception was a study conducted by Rodahl, et al (70) on a sample of 601 children and young adults from the Philadelphia area. The students who participated in these tests were selected according to a table of random numbers from alphabetical lists. Of these subjects, 126 were measured for maximal oxygen uptake on a bicycle ergometer and compared with results obtained in Germany and Sweden. Several conclusions resulted: 1) in general, students from north Philadelphia schools were superior to students from south Philadelphia schools; 2) there is little difference between boys and girls up to the ages 10 to 12 in physical work capacity, but after that there is a marked difference; 3) in general the pulse response to a given work load indicated inferior physical fitness in the Philadelphia subjects when compared with the Swedish subjects; 4) the results of the Philadelphia data are comparable to the results obtained by Freiburg in Germany; 5) there were significant differences between females 20 to 22 years in Philadelphia and in females 20 to 29 years in Sweden; 6) in view of the significant differences that were found in work capacity between different cities and between different schools, caution must be exercised when comparing countries.

Adams, et al (2) and Cumming, et al (32,33) have conducted studies in North American using a different aspect of working capacity. Their method, as developed by Sjöstrand (77) was to let the subject work on a

bicycle ergometer for six minutes on each of a series of increasing work loads until the pulse rate reached a level of 150 to 170 beats per minute. With this method the physical working capacity was indicated to the power level where the pulse rate after extrapolation is 170 beats per minute.

Adams, et al (2) used 120 male and 123 female students, ages 6 to 14, as subjects. The technique of random selection used was that every third student by sex in an elementary school and every fifth student by sex in a Junior High school was studied. They found that working capacity increased with age, height, weight and body surface area. The best correlations were with the logarithm of the surface area and with the logarithm of the weight. These were, for boys, 0.81 and 0.81, and for girls, 0.80 and 0.77. A similar study (1) was done on 196 country and city school children, ages 10, 11 and 12 years, in Sweden. The results showed: 1) the difference between the regression lines of both the country girls and boys and the city girls as significant ($p<0.01$); 2) in the case of both boys and girls, for both city and country, the working capacity was significantly greater with increasing degree of physical training; 3) the physical working capacity was found to increase with age, height, weight, surface area, heart volume and degree of physical fitness; 4) there was no significant difference in the slopes of the regression lines for working capacity and surface area of the country and city boys; 5) a significant difference was found at the 2 per cent level for country and city girls; 6) no case can be made for the Swedish boys having greater working capacities than a comparable group of California boys; and 7) a significant difference at the 1 per cent level for Swedish country girls and the California girls was found.

Cumming and Cumming (32) have done a study on 200 Winnipeg school children. The study consisted of two parts. In the first part students from ten different schools were selected by the classroom teacher according to whether the student was poor, average, or good in physical ability. In the second part, 88 sixth grade students, age 11 and 12 years, were selected and divided into classes A, B, C, and D. Classes A, B, and C were students from public schools rated as to scholastic ability and socio-economic environment. Class D indicated a private school with a superior physical education program. In general, the results indicated that; 1) there was a high correlation of the working capacities of the boys with their height (0.865), weight (0.897) and surface area (0.904); 2) these correlations were not as high in the case of girls; 3) the male students high in scholastic ability and in a high income area ranked 8 per cent lower than the average classes (the difference was not statistically significant); 4) in the private school the maximum work capacity was 13 per cent higher than the average class (the difference however was not statistically significant); 5) the female students high in scholastic ability and in a high income area ranked 16 per cent lower than the average class in the same school, ($p < .05$); 6) when compared with California and Swedish students the working capacities of the 11 and 12 year old boys and girls tended to be smaller; and 7) the working capacities of the 40 nurses studied ranked 42 per cent lower than a group of Swedish women.

The literature indicates that much more research in this area is needed before statements regarding differences in work capacities can be made with any degree of confidence.

CHAPTER III

METHODS AND PROCEDURE

Subjects

The subjects selected for the problem were part of a sample of secondary school students in the Province of Alberta. The sample was chosen in consultation with Mr. G. Ustinov of the Alberta Branch of the Dominion Bureau of Statistics. This sample was similar to that used by the Alberta Government in their labor force studies and represented areas chosen on geographical, social and economic criteria (55). This sample, deemed to be representative of the secondary school population of Alberta, was composed of 3 per cent of the total population of the 45 city, town, and village schools included in the sample.

T.C. Byrne, Superintendent of Public Schools for the Province of Alberta, was approached and formal permission was granted to enter the various schools included in the study and carry out the necessary testing. Letters were then sent to the principals and superintendents of the schools concerned in the study, asking permission to enter the schools under their jurisdiction. Information relative to the study, such as the number of subjects to be tested and the testing time was also included in each letter. Similar procedures were used for the separate schools involved in the study.

The actual selection of subjects from each school was based on a random technique outlined by Garrett (47). Class lists from each school were obtained and arranged in alphabetical order according to grade. Each student in the school was numbered and selected according to a table of random numbers. In instances where a student had withdrawn or was absent from school, alternates were chosen. In all 1024 students throughout

the Province were tested, and of these 917 were accepted as meeting the criteria of the test.

The subjects used for the subsidiary problems were selected from the population of students enrolled in the Edmonton secondary school. Where possible, students previously tested in the main problem were used again. At the time of the initial test the subjects were questioned as to whether or not they would be interested in being part of an additional study which was to be conducted during the months of July and August. Prior to the commencement of the summer testing session, students who had indicated an interest and who resided relatively close to the University of Alberta were contacted and their willingness to undergo additional tests determined. Due to an unexpected number of rejected subjects, declared unfit to engage in strenuous exercise for medical reasons, it was necessary, towards the end of the testing schedule, to solicit subjects who were not part of the main study but who were secondary school students. In this way, the desired number of males and females were tested.

Time and Duration of the Study.

The testing of the secondary school subjects commenced on April 14, 1964, and continued until June 5, 1964.

The testing for the subsidiary problems was carried out at the University of Alberta during July and August of 1964.

Predicted Test Apparatus.

The following apparatus for the Astrand sub-maximal test was used: (1) a Monark bicycle ergometer; (2) an electrical metronome; (3) two stop watches calibrated to 1/10 of a second; (4) a tape measure; (5) a Borg scale; (6) a University of Alberta truck used to transport the equipment to the various schools.

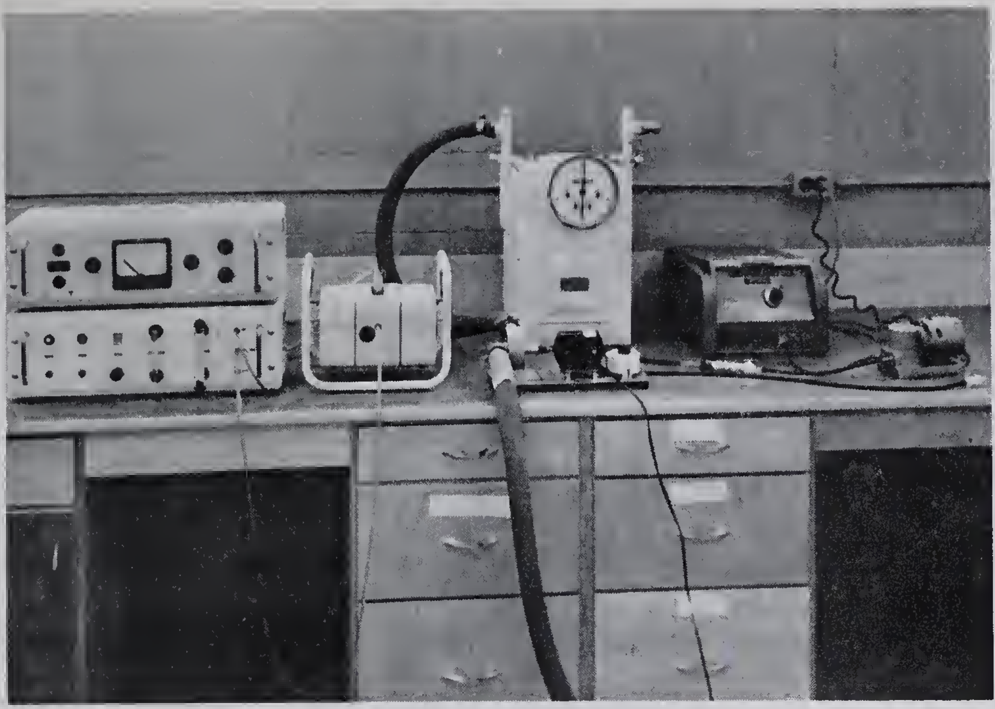


FIGURE III – i Godart CO_2 Analyzer, Volume Meter, Beckman E–z O_2 Analyzer

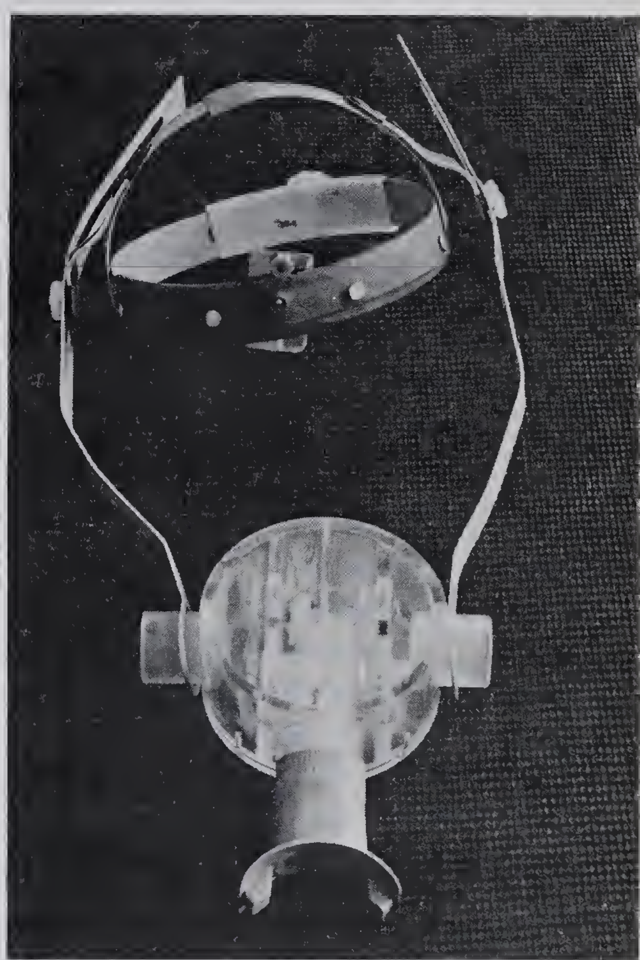


FIGURE III – ii Modified Otis McKerrow Valve with light weight head gear.

FIGURE III – iii Monark GCI Bicycle Ergometer

Test Methods and Procedures.

Main Problem. Where possible, pre-arranged schedules of the students to be tested and the testing time for each student were drawn up and delivered to the schools a day before the school was to be visited. If possible the Nurse's room was used for testing purposes, but in many cases, vacant rooms had to be accepted.

When the subject entered the testing area he/she was given a preliminary briefing as to what the test involved. His/her height and weight were then taken and other information as to residence, age, smoking habits and recreational activities was asked. Where the students did not report in gynasium dress they were permitted to take the test as they appeared. Gynasium suits were provided and used by those who preferred to do so.

Any subject who was medically unfit was excused from the test and an alternate was selected.

The test itself was administered, with the bicycle standing on a level firm foundation, in the following manner: (see figure III-iii). The subject mounted the bicycle and his/her pre-exercise pulse rate was taken. The saddle was then adjusted such that when the test subject had the front part of the sole of his/her foot on the pedal, there was a slight bend of the knee-joint in the lower position. With the test person mounted on the bicycle, but without his/her feet touching the pedals, the "O" mark on the work scale was adjusted so that it coincided with a mark on the pendulum weight. The metronome, set at exactly 100 single beats per minute, was started and the subject was instructed to begin cycling in rhythm with the metronome (see Figure III-v).

When the subject was able to pedal in cadence with the metronome, the work load was then set in accordance with the sex and size of the

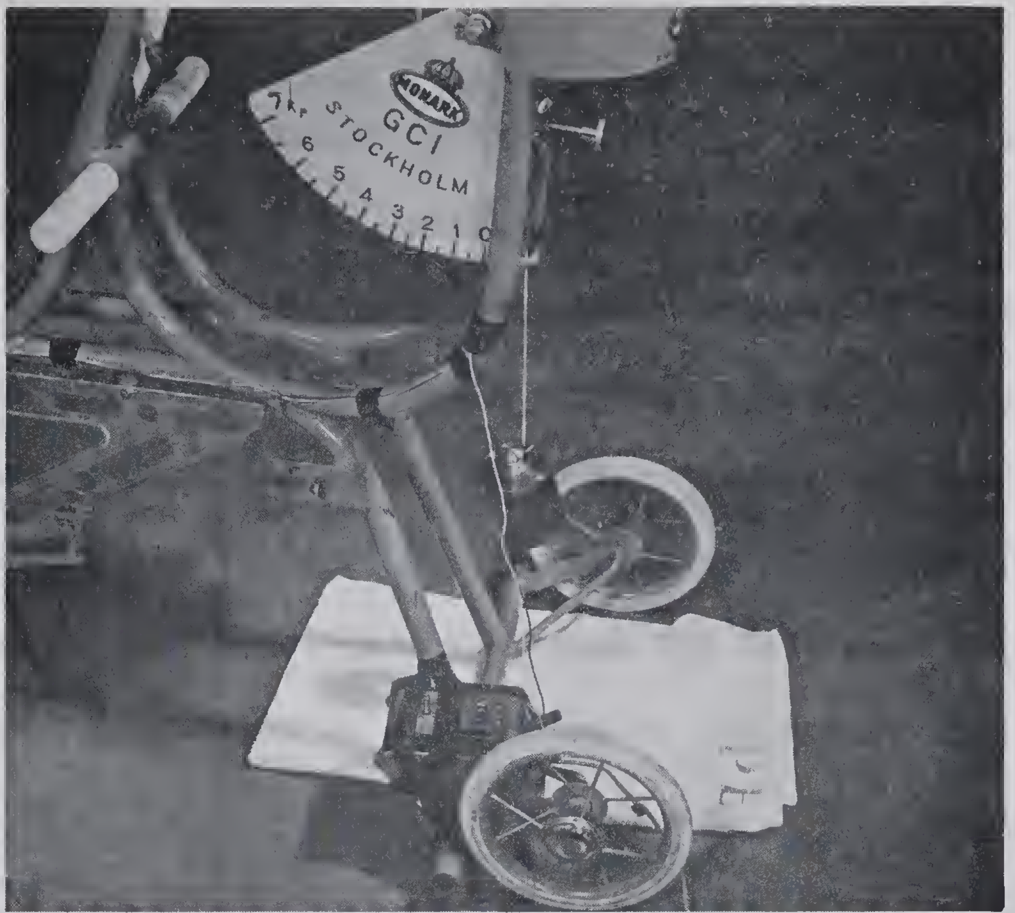


FIGURE III – iv Calibration of Monark Bicycle using 2 kilogram weight.

FIGURE III – v Astrand–Ryhming predicted maximal oxygen intake test. Note: palpation heart rate technique, placement of electrodes for female subject, metronome, electrocardiograph.

subject. The load was increased if the pulse rate did not exceed 120 beats per minute. The pulse rate was established by taking the time for a 30 beat complex, using palpation over the carotid artery, and converting the time to beats per minute using a table supplied by Astrand (14).

If the pulse rate exceeded 120 beats per minute, the work load was considered adequate and the test was discontinued after 6 minutes, providing the heart rate had remained constant between the fifth and sixth minute. If this "steady state" (plus or minus 5 beats) was not reached the test was prolonged until a constant level was attained. The working pulse was calculated by taking the average of two pulse rates in a steady state. This mean pulse rate was then corrected for the error that resulted due to the palpation method of determining heart rate. Tables developed by Astrand (3) enabled the maximal oxygen intake to be calculated. In each case, this predicted value was multiplied by 1.10, a factor designed to correct for an underestimation of the actual value due to the age of the subjects.

Subsidiary Problem. When the subjects to be used in the subsidiary problem were contacted, a time was arranged when they would be delivered to the University Hospital where medical examinations were to be administered. These medical sessions were conducted twice weekly and for each session a group of from 10 to 14 subjects received their examinations. Those subjects who were declared fit to participate in the tests that were to follow (about 20 per cent were rejected) were then scheduled for their initial test. Typewritten sheets with an explanation of the type and severity of the tests and permission slips to be signed by the respective parents were issued to the subjects at this time.

Each subject was tested twice. One test was similar to the submaximal

test previously administered and the other test was the Astrand actual test of maximal oxygen consumption. This actual test was modified, where necessary, in such a way that the initial work load corresponded to that used for the submaximal test.

The order in which the tests were administered for each subject was randomly determined. Except where circumstances prevented, the two tests were conducted within three to four days of each other. In this way it was possible to complete the testing of one group of subjects before another group was delivered for their medical examinations and the possibility of the work capacity of individuals changing between the two tests was lessened.

The procedure for the submaximal test was essentially the same as previously described for the main problem. In addition to palpation determinations of heart rate, recordings were also made by means of a SANBORN electrocardiogram. These recordings were synchronized with the palpation determinations so that heart rates under both methods were determined for an identical period. During the maximal test a similar procedure was also employed.

At the end of the testing schedule, the palpated and electrocardiogram recordings were compared for each investigator involved in taking heart rates by palpation (see Figure III-vii).

Correlation coefficients were calculated and regression lines established. By this procedure, it was possible to correct each of the palpation determinations of heart rate so that a closer approximation to the actual rate resulted. This new "steady state" heart rate was then used, in all submaximal tests administered, to predict the maximal oxygen value from the nomogram.

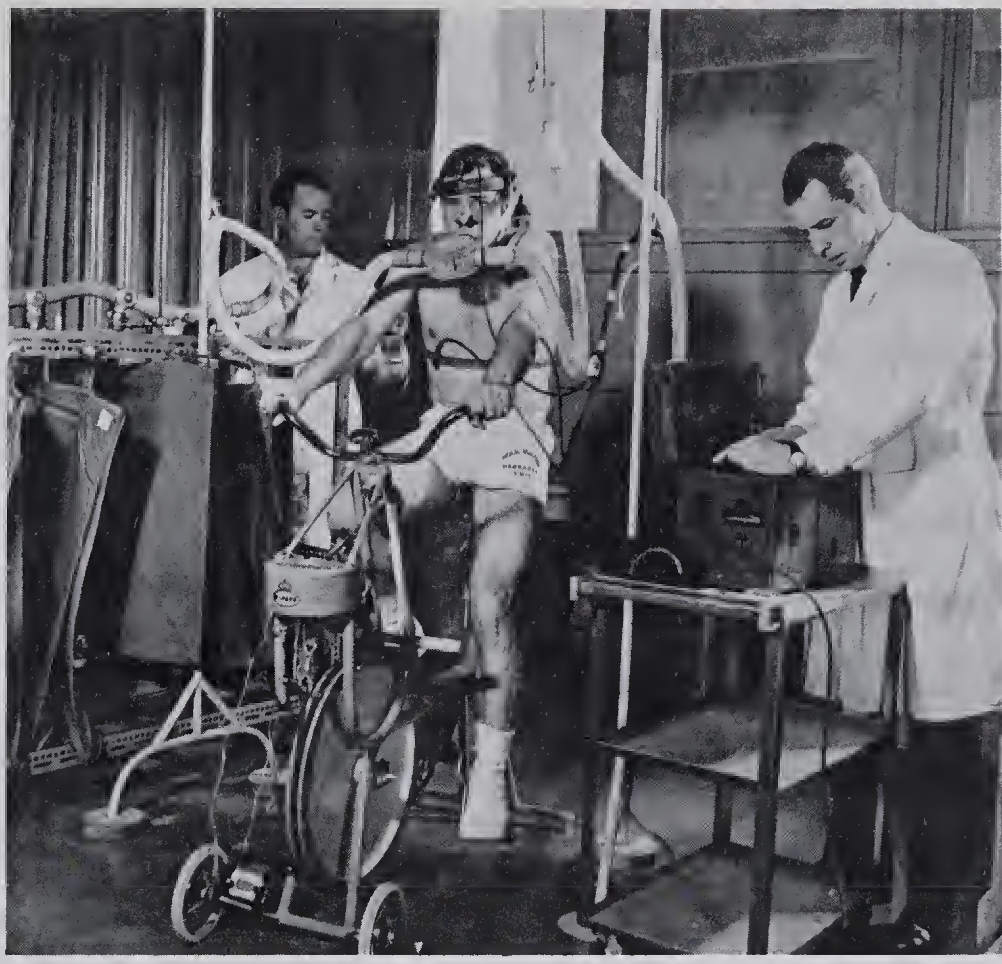


FIGURE III – vi Astrand actual maximal oxygen intake test. Note placement of electrodes for male subject.

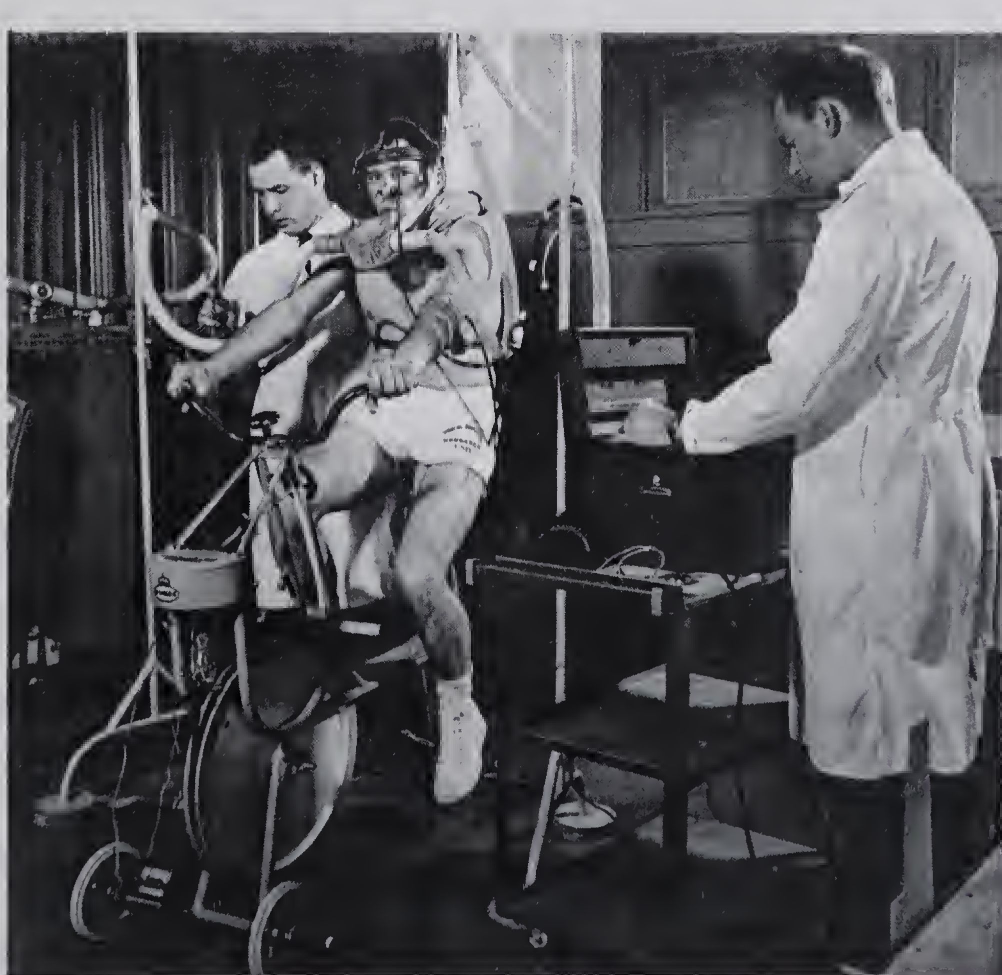


FIGURE III – vii Palpation heart rate technique during Astrand actual test.

Following the submaximal test, each subject was tested for knee extensor strength by means of the cable tensiometer technique as described by Clarke (29). The subject assumed a sitting, backward-leaning position on the padded table with his/her arms extended to the rear and his/her hands grasping the sides of the table. The knee being tested was extended to 115 degrees, determined by means of a goniometer, while the leg not being tested hung freely from the end of the table. The regulation strap was placed midway between the knee and the ankle joints. The pulling assembly was attached to the hook at the lower end of the table. The subject was prevented from lifting his/her buttocks and/or flexing his/her arms.

The subject was encouraged verbally to exert a maximum effort at all times during the test. The strength of the muscle group being tested was determined by measuring the force required to create offset in a cable between two set points. This force was converted to pounds through the use of a calibration chart. Each subject was given three trials with each leg and the average pull for each leg was calculated and recorded as the strength of the leg at that time (89). For the purposes of this study these two average values were combined and the mean average strength for both legs obtained. The testing proceeded as follows: the measurement of 3 right leg extensions followed by 3 left leg extensions. Each subject was allowed a two minute rest between each maximal contraction.

<u>Actual Test Apparatus</u>. The following apparatus was used for the Astrand actual maximal oxygen intake test: 1) a Monark bicycle ergometer; 2) a stop watch calibrated to 1/10 of a second; 3) a time clock; 4) a metronome; 5) a Beckman E2 oxygen analyzer; 6) N.V. Godart Capnograph; 7) Douglas bags; and 8) a Sanborn electrocardiogram.

Test Methods and Procedures. The method of determining the maximal oxygen uptake was essentially the same as used by Astrand (11) with slight modification. The test procedure was similar to that described for the predicted test in that the subjects worked at a set work load and pedalled in time to an electric metronome set at 100 beats per minute. Douglas bags were used to collect expired air and heart rates were taken on a Sanborn electrocardiogram (see Figure III-vi).

When the subject reported for the actual test, pre-exercise heart rates and resting oxygen consumption values were taken from a sitting position on the bicycle ergometer. The beginning work load was determined (usually set at 600 kpm for the males and 300 kpm for the females) and the subject began to pedal in time with the metronome. In cases where the isolated submaximal test was administered before the maximal test, it was necessary that the work loads for the two tests be identical. From the fourth to the fifth minute the subject was connected to an OTIS-MCKERROW two-way breathing valve by means of a rubber mouth-piece and expired air was collected from the fifth to the sixth minute. For this work load palpation and electrocardiogram determinations of heart rate, as outlined for the submaximal test, was also taken.

The six minute ride was alternated with a five minute rest during which time the expired air was analyzed and the subject's oxygen consumption calculated. The work load was raised, by increments of 150 or 300 kpm, depending on the size and sex of the subject, and a second six minute ride ensued. The above procedure was repeated at increasing work loads until the oxygen intake levelled off or declined or until the subject was unable to continue. The criteria designating maximal oxygen intake was that the difference between two successive analysis at different work levels

was less than 80 millilitres of oxygen per minute.

If the subject found it impossible to continue for the required duration at a given work load, a gas sample was taken at an earlier period. Where possible a full minute of expired gas was captured, but where a sample was taken for only a fraction of this time, the necessary calculations were performed to equate this volume to a minute volume.

In cases where the subject had obtained a maximal oxygen value, as defined by the criterion of the test, he/she was asked to attempt an additional work load. In this way it was possible to determine any changes in further oxygen uptake as a result of additional effort beyond that required by the test.

Method of Determining Maximal Oxygen Consumption. The expired air in the Douglas bags was analyzed for the percentage of oxygen by drawing a sample of expired air into a BECKMAN #E-2 oxygen analyzer. The percentage of carbon dioxide was determined by the same procedure, using a #KK Godart Capnograph infra-red carbon dioxide analyzer. Both gas analyzers were carefully calibrated prior to use and in many instances double determinations were taken and compared. The volume of expired air was determined by passing the contents of the bag used through an #802 American Meter Company Gasometer at a constant rate of 70 litres per minute with a COLLINS #p-533, 1/15 horse power centrifugal pump (see Figure III-i).

Pulmonary ventilation was expressed as litres of air expired per minute, the volume of gas being reduced to the standard temperature and pressure 0°C and 760 mm Hg, dry. The formula used was (30:373):

$$\frac{P_B - P_{H2O}}{760(1 + 0.00367T)}$$

where: P_B = ambient barometric pressure.

P_{H2O} = the vapor tension of water, mm Hg. at the temperature of the gasometer

T = the temperature of the gasometer, ^{o}C.

The oxygen consumption was calculated by the following method as cited in (49).

1) Corrected volume of expired air is

Ve air STPD = Ve ATPS x the factor for reducing a volume of moist gas to a volume of dry gas at $0^{o}C$, and 760 mm.

2) The correction per cent of oxygen in the expired air is

$$FeO_2 = \text{Analyzer reading} \times \frac{2.5}{1000}$$

3) The volume of inspired air is

$$Vi\ air\ STPD - Ve\ air\ STPD \times \frac{FeN_2}{F.N_2} \quad \text{where } F.N_2 = 79.03$$

4) The total volume of oxygen inspired is

$$ViO_2 - Vi\ air \times \frac{F.O_2}{100} \quad \text{where } F.O_2 = 20.94$$

5) The volume of expired oxygen is

$$VeV_2 = \frac{FeO_2}{100} \times Ve\ air$$

6) The amount of oxygen consumed is

$$VO_2 = ViO_2 - VeO_2$$

where:

A) Fe = % of a particular gas in expired air.

B) Fi = % of a particular gas in inspired air.

C) Ve = Volume expired.

D) Vi = Volume inspired.

E) ATPS = Atmospheric temperature, pressure, saturated.

F) STPD = Standard temperature, pressure saturated.

G) STP = Standard pressure, temperature.

Calibration of Instruments and Accuracy of Calibration Gases.

Bicycle Ergometer. The sinus balance was calibrated by means of a set of stainless steel weights, #750 Class S-1, Serial No. 7Y1458 (see Figure III-iv) in the following manner (14:3):

a) The brake drum was removed and the mark on the pendulum weight was set at "0".

b) A one kilogram weight was attached to the spring as shown on Figure III-iv. Weights were added or taken from the spring as required to bring the mark on the pendulum to the required scale mark of "1-kp".

c) If adjustment was required it was made by means of an adjusting screw which altered the center of gravity of the sinus balance.

American Volume Meter and Collins Centrifugal Pump. The rate of flow through the #802 American Meter Company Gasometer was checked by evacuating a known quantity of gas from a Collins Chain-Compensated Gasometer with a capacity of 120 litres and a factor of 133.2 cc/min.

Calibration Gases for the Beckman E-2 Oxygen Analyzer and Godart Capnograph Carbondioxide Analyzer. The calibration gases used for calibrating the two instruments were evaluated several times by means of analytical procedure outlined by Scholander (75). The tests were carried out by the laboratory technician in the Department of Physiology and the Cardio-Pulmonary laboratory of the University of Alberta hospital.

Statistical Treatment. For the main problem, t tests were used to determine the significance of the difference between the means of the rural

and urban samples studied (45). The samples were then divided into age categories and additional independent t- tests were computed to determine the significance of the difference by age and sex. In all cases, the critical level for significance selected was .05.

For the subsidiary problems, Pearson product-moment correlation coefficients (45) were computed between heart rate, work load and oxygen consumption and between work performed, strength, predicted maximal oxygen intake and measured maximal oxygen intake.

An analysis for trend (43) was carried out for each of heart rate and work load and oxygen consumption and work load. F ratios were computed to determine if there was a statistically significant linear and/or quadratic trend for these values.

CHAPTER IV

RESULTS AND DISCUSSION

Results

Mean values for height and weight. The mean values for height and weight of the rural and urban samples included in the study are given in Table III.

TABLE III

DATA FOR HEIGHT AND WEIGHT

Parameter	Age	Urban Male	Urban Female	Rural Male	Rural Female
Height (inches)	14,15,16	68.49[a]	64.21	68.33	63.69
	17	69.01	64.11	69.45	64.10
	18,19,20	69.59	63.94	70.07	64.88
Weight (kilograms)	14,15,16	63.08	55.00	62.82	54.94
	17	65.89	55.00	65.42	58.21
	18,19,20	67.71	56.59	73.31	57.57

[a] Mean value.

Means and standard deviations for the predicted maximal oxygen consumption test. Table IV gives the mean values, standard deviations, T values and percentage differences between the rural and urban samples obtained for both sexes on the predicted maximal oxygen consumption test.

TABLE IV

MEAN PREDICTED OXYGEN CONSUMPTION VALUES FOR BOTH SEXES

	N	Urban Mean ±S.D	N	Rural Mean ±S.D	T-Value	Percent Difference
Litres/Min.						
Male	444	2.91 ± .59[b]	56	3.20 ± .64	3.38[a]	8.93
Female	365	2.03 ± .41	52	2.16 ± .43	2.08[a]	5.90
Ml/kg./min.						
Male	443	45.36 ± 8.86	56	47.79 ± 8.59	1.94	5.09
Female	365	37.15 ± 7.26	52	38.46 ± 8.06	1.20	3.40

[a]Statistically significant at the .05 level of confidence.

[b]Mean ± Standard Deviation

A test of significance for homogeneity of variance (43) for each of the male and female samples demonstrated that the variances were not significantly different ($p = .05$). It was concluded that the assumption of homogeneity between the variance estimates was tenable.

For the 444 urban and the 56 rural male subjects included in the sample, the mean predicted oxygen consumption values were 2.91 and 3.20 litres per minute respectively. When body weight was considered these values became 45.36 and 47.79 millilitres per kilogram. For 365 urban and 52 rural female subjects these values were 2.03 and 2.16 litres per minute and 37.15 and 38.46 millilitres per kilogram minute.

The differences in these mean predicted values when expressed in litres per minute, showed significance ($p = .05$) for both the males and the females. When these mean values were expressed in millilitres per kilogram of body weight and tests of significance again computed, no

significant differences ($p = .05$) were detected.

The percentage difference $\left(\frac{\text{rural value} - \text{urban value} \times 100\%}{\text{rural value}}\right)$ between the rural and urban males in predicted litres per minute of oxygen consumption was 8.93 percent. This difference was reduced to 5.09 percent when the values were expressed in millilitres per kilogram of body weight.

The females demonstrated a similar tendency. A difference of 5.90 percent was shown when the mean values were expressed in litres per minute and this was reduced to 3.40 percent when body weight was considered.

Means and standard deviations for males according to age groups on the predicted maximal oxygen consumption test. Table V gives the mean values, standard deviations, T-values and percentage differences for the male urban and rural age groupings on the predicted maximal oxygen consumption test.

TABLE V

MEAN PREDICTED MAXIMAL OXYGEN CONSUMPTION VALUES FOR MALES

Age	N	Urban Mean ± S.D.	N	Rural Mean ± S.D.	T-Value	Percent Difference
14,15,16						
Litres/min	199	2.88 ± .56[b]	15	3.02 ± .65	0.99	4.94
Ml/kg/min	199	46.11 ± 8.92	15	48.23 ± 6.70	0.90	4.39
17						
Litres/min	142	2.95 ± .60	20	3.27 ± .67	2.18[a]	9.75
Ml/kg/min	141	45.01 ± 9.25	20	50.41 ± 9.16	2.46[a]	10.72
18,19,20						
Litres/min	103	2.94 ± .63	21	3.26 ± .60	2.12[a]	9.77
Ml/kg/min	103	44.37 ± 8.11	21	44.98 ± 8.74	0.31	1.36

[a]Statistically significant at the .05 level of confidence.

[b]Mean ± standard deviation.

For the age groups considered, the rural samples demonstrated a consistently greater mean capacity for oxygen consumption whether the values were expressed as an absolute measure in litres per minute or as a relative measure im millilitres per kilogram of body weight.

The rural values, expressed in litres per minute and in millilitres per kilogram of body weight, were 3.02 and 48.23 for the age group 14-16 inclusive; 3.27 and 50.41 for the 17 year-old group, and 3.26 and 44.98 for the age group 18-20 inclusive. The comparable urban groups showed values of 2.88 and 46.11, 2.95 and 45.01, and 2.94 and 44.37 respectively.

A t-test (45) was carried out for each age group in order to test the differences between the rural and urban mean values for significance. When these mean values were expressed in litres per minute significant differences ($p = .05$) were found for both the 17 and 18-20 year old age groups. When the mean values were divided by body weight a significant difference ($p = .05$) was found only for the 17 year old age group.

The inclusion of the variable "body weight" into the measures of predicted maximal oxygen consumption resulted in a reduction of the percentage differences between the rural and urban age groups. One exception was observed for the 17 year old group in which the percentage differences increased from 9.75 to 10.72.

<u>Means and standard deviations for females according to age groups on the predicted maximal oxygen consumption test</u>. Table VI gives the mean values, standard deviations, T values and percentage differences of the female urban and rural age groupings on the predicted maximal oxygen consumption

TABLE VI

MEAN PREDICTED MAXIMAL OXYGEN CONSUMPTION VALUES FOR FEMALES

Age	N	Urban Mean ± S.D.	N	Rural Mean ± S.D.	T-Value	Percent Difference
14,15,16						
Litres/min	212	2.00 ± .39[a]	23	2.13 ± .44	1.56	6.33
Ml/kg/min	212	36.54 ± 6.87	23	38.99 ± 9.28	1.56	6.28
17						
Litres/min	117	2.08 ± .41	14	2.24 ± .34	1.38	7.01
Ml/kg/min	117	38.27 ± 7.48	14	39.24 ± 4.96	0.47	2.48
18,19,20						
Litres/min	36	2.08 ± .25	15	2.13 ± .51	0.28	2.10
Ml/kg/min	36	37.10 ± 8.50	15	36.91 ± 8.66	0.07	-.52

[a]Mean ± standard deviation.

test.

Following the procedure employed for the male sample, the female sample was also divided into age groups of 14-16 years inclusive, 17 years and 18-20 years inclusive. The rural maximal oxygen consumption values for these three groups were 2.13, 2.24, and 2.13 litres per minute and 38.99, 39.24, and 36.91 millilitres per kilogram of body weight respectively. The urban values expressed in litres per minute and in millilitres per kilogram of body weight were: for the 14-16 year group, 2.00 and 36.54, for the 17 year old group, 2.08 and 38.27, and for the 18-20 year group, 2.08, and 37.10.

No significant differences (p = .05) between the urban and rural mean values were found at any age level when t-values were computed.

This applied when the mean values were expressed either in litres per minute or in millilitres per kilogram minute.

When body weight was considered in the calculation of these predicted values, the percentage difference between the rural and urban samples was reduced. For the 14-16 year group, this difference decreased from 6.33 to 6.28 percent. Similarly, for the 17 and 18-20 year groups, this decrease was from 7.01 to 2.48 percent and from 2.10 to -.52 percent respectively.

The larger maximal oxygen value, 37.10 to 36.91 millilitres per kilogram, displayed by the 18-20 year urban group represented the only instance in the entire sample in which an urban group had a greater value than its comparable rural group.

<u>The relationship between heart rate, work load, and oxygen consumption</u>. Pearson Product-moment correlation coefficients were calculated in order to determine the degree of linear relationship between heart rate, work load, and oxygen consumption over a range of values. In each case, the investigation of this relationship was limited to those subjects who had performed at identical work loads, i.e., for the males, 600, 900, and 1,200 kilopond metres and, for the females, 300, 600, and 750 kilopond metres.

The correlation coefficient obtained between heart rate and oxygen consumption for ten males who performed an equal amount of work was 0.95. When heart rate and work load were compared, this relationship gave a coefficient of 0.94, whereas for work load and oxygen consumption the value was 0.97.

TABLE VII

CORRELATION COEFFICIENTS OBTAINED BETWEEN HEART RATE, WORK LOAD AND OXYGEN CONSUMPTION

		Oxygen Consumption	Work Load
Heart Rate	Males	0.95	0.94
	Females		
Work Load	Males	0.97	
	Females	0.91	

For fourteen female subjects the correlation coefficient between work load and oxygen consumption was 0.91.

It should be noted that although the females pedalled at identical work loads, the total work performed by each subject was not the same. The determination of the relationship between heart rate and the values of oxygen consumption and work load was not possible due to a large number of illegible electrocardiograph recordings.

Although the high correlation coefficients reported between heart rate, work load and oxygen consumption indicated that there was a high linear relationship between any two of these variables, they did not indicate if there was a significant deviation from this trend. Tables VIII, IX and X summarize the results of three trend analysis tests carried out to determine if there was a significant deviation of heart rate and/or oxygen consumption from linearity over the three work loads studied.

TABLE VIII

TREND ANALYSIS OF HEART RATE FOR MALES OVER THE WORK LOADS 600, 900 AND 1200 KILOPOND METRES

Source of Variation	Sum of Squares	df	Mean Square	F
Linear Component	16,302.05	1	16,302.05	519.67[a]
Quadratic Component	28.02	1	28.02	.89
Subjects	1,546.30	9	171.81	
Subjects x work loads	564.60	18	31.37	
Total	18,440.97	29		

[a]Statistically significant at the .005 level of confidence.

TABLE IX

TREND ANALYSIS OF OXYGEN CONSUMPTION FOR MALES OVER THE WORK LOADS 600, 900, and 1200 KILOPOND METRES

Source of Variation	Sum of Squares	df	Mean of Square	F
Linear Component	12.1992	1	12.1992	960.57[a]
Quadratic Component	.0913	1	.0913	7.19[b]
Subjects	.3994	9	.0443	
Subjects x work loads	.2277	18	.0127	
Total	12.9176	29		

[a]Statistically significant at the .005 level of confidence.

[b]Statistically significant at the .05 level of confidence.

TABLE X

TREND ANALYSIS OF OXYGEN CONSUMPTION FOR FEMALES OVER THE WORK LOADS 300, 600, AND 900 KILOPOND METRES

Source of Variation	Sum of Squares	df	Mean of Squares	F
Linear Component	6.4320	1	6.4320	190.30[a]
Quadratic component	.4032	1	.4032	11.93[a]
Subjects	.7952	13	.0612	
Subjects x work loads	.8783	26	.0338	
Total	8.5087	41		

[a]Statistically significant at the .005 level of confidence.

The results of the trend analysis tests indicated that there was a highly significant linear trend (p = .005) for both oxygen consumption and heart rate over the three work loads investigated.

For the males, there was a non-significant quadratic component when heart rate was analyzed with work load. This meant that the relationship between these two variables could be quite accurately represented by a straight line. When the oxygen consumption values were investigated in order to determine their response to increasing work load, a significant deviation from linearity was found (p = .05). As a result, it was inferred that at high work loads the oxygen consumption values tended towards a quadratic function as the individuals' maximal capacity was approached. For the female subjects only one trend test was possible due to insufficient heart rate data. It was found that, although the increase in oxygen consumption values over increasing work loads showed a

highly significant linear trend ($p = .005$), a highly significant quadratic trend ($p = .005$) was also evident. This was not surprising in view of the fact that the highest work load of 900 kilopond metres represented the level at which many subjects attained their maximal oxygen consumption value.

It was necessary to use values of oxygen consumption compiled over the work loads of 300, 600, and 900 kilopond metres because one of the prerequisites to using a trend analysis test is that the differences between the ordered variable, in this case work load, must be equal.

Correlation coefficients obtained between work performed, strength and the actual and predicted maximal oxygen consumption values. The relationship between work performed and strength with the actual and predicted values, expressed in litres per minute, are given in Table XI. Work performed above 900 kilopond metres for the males and 600 for the females, and expressed in kilopond metre minutes, was calculated by summing the product of the work load times the minutes pedalled at each level to the level of the individuals' maximal oxygen value.

The average strength index, expressed in pounds, was determined by summing the strength scores for each leg and dividing by the total number of trials.

The results showed that for the twenty-six male subjects studied, the relationship between the maximal oxygen consumption (the value used to indicate the subject's maximal capacity whether the test criterion had been reached or not) and the work performed to attain this value gave a correlation coefficient of 0.69. This value was found to be significantly

TABLE XI

CORRELATION COEFFICIENTS OBTAINED BETWEEN WORK PERFORMED AND STRENGTH WTIH THE ACTUAL AND PREDICTED MAXIMAL OXYGEN CONSUMPTION VALUES

		Maximal Oxygen Consumption			
		Recorded	Criterion	Predicted	Strength
Work Performed	Male	0.69[a]	0.61[b]		0.51[c]
	Female	0.68[b]	0.68[c]		0.48
Strength	Male	0.34		0.03	
	Female	0.37		0.46	

[a]Statistically significant at the .001 level of confidence.

[b]Statistically significant at the .01 level of confidence.

[c]Statistically significant at the .05 level of confidence.

different from zero beyond the .001 level of confidence.

The sixteen female subjects demonstrated a similar relationship between these two variables. The obtained correlation coefficient of 0.68 was found to be significantly different from zero beyond the .01 level of confidence.

These statistically significant correlation coefficients indicated that a functional relationship existed between the individual's measured maximal oxygen consumption and the work performed to attain this value.

Additional Pearson Product-moment correlation coefficients were computed to determine the degree of relationship between the criterion maximal oxygen consumption values as determined by the Astrand actual test and the work performed in reaching these values. For twenty-one

male subjects, the relationship between these two variables was 0.61 and for twelve female subjects, 0.68. These coefficients were significantly different from zero at the .01 and .05 levels of confidence respectively.

When this measure of work performance was correlated with the average strength index, coefficients of 0.51 for the males and 0.48 for the females were obtained. A test of significance showed that only the larger of these coefficients was significantly different from zero ($p = .05$). The correlation between strength and the determined maximal oxygen uptake value gave coefficients of 0.34 for the males and 0.37 for the females. Neither of these coefficients was found to be significantly different from zero.

In order to determine whether the measure of strength was functionally related to the maximal oxygen consumption value predicted from the submaximal test, correlation coefficients were computed on eighteen male and sixteen female subjects. Although statistical significance was not shown in either instance, the females (0.46) demonstrated a greater relationship between these two variables than did the males (0.03).

Analysis of the maximal oxygen consumption values. A subsidiary problem of this study was to analyze the effect of continued work on the oxygen consumption of a subject after his/her maximal value, as defined by the criterion of the Astrand actual test (11) had been reached. Table XII gives the highest oxygen values obtained for each male subject, as well as the criterion values and the exhaustion values for those subjects who performed work beyond that required by the test.

TABLE XII

HIGHEST, CRITERION, AND EXHAUSTION OXYGEN CONSUMPTION VALUES FOR MALES OBTAINED ON THE ASTRAND ACTUAL TEST

	Oxygen Consumption (litres/min)						
Subject	Highest	Criterion	Exhaustion	Subject	Highest	Criterion	Exhaustion
1	3.697	3.697		16	3.213	3.211	3.213[a]
2	3.146	3.146		17	3.067	2.839	3.067[a]
3	3.407	3.407	3.251	18	3.504[b]		
4	2.851	2.851	2.518	19	2.484	2.484	
5	1.925	1.875	1.925[a]	20	3.066	3.066	2.721
6	2.349	2.273	2.349[a]	21	3.259[b]		
7	3.168	3.168		22	3.180	3.180	2.795
8	3.706[b]			23	3.465	3.465	
9	2.863[b]			24	3.269	3.184	3.269[a]
10	2.806[b]			25	3.254	3.254	
11	3.341	3.341	3.188	26	--		
12	2.887	2.887		27	2.593	2.593	2.240
13	2.879	2.879		28	3.190[b]		
14	3.581	3.581	3.370	29	3.113[b]		
15	2.898	2.898	2.831	30	2.023	2.023	

[a]Increased oxygen consumption above criterion value.

[b]Continued to increase by more than 0.080 litres throughout the test.

Astrand (11) has outlined that the criterion for evaluating a subject's maximal level for oxygen uptake is that the oxygen uptake does not increase despite a rising work load, but reaches a level. For the Astrand actual test this level was said to have been reached when the values of two successive oxygen intake recordings did not increase by any more than 0.080 litres.

For the male subjects, of the twenty-nine oxygen consumption values recorded, twenty-two exhibited values which actually met the stated criterion of the test. The values for the remaining seven subjects

demonstrated consistent increases greater than 0.080 litres throughout the test.

Thirteen subjects who had reached a criterion oxygen uptake value were able to perform at an additional work level for varying periods of time. As illustrated in Table XII, four of these subjects increased their oxygen uptake value, one levelled off and the remaining eight decreased. Two of these four increases, representing 50 and 76 millilitres, were still within the range of the accepted criterion of the test, while the remaining two increases, representing 85 and 328 millilitres, demonstrated that the subject's maximal aerobic capacity had not been reached initially.

Seven subjects continued to increase their oxygen uptake values throughout the test and did not reach a maximal criterion value. These values, therefore, must be questioned as representing the subject's maximal oxygen consumption value.

The mean maximal heart rate for twenty-five of these male subjects was 193.4 beats per minute with a range of 178-210 beats per minute.

Table XIII gives the highest oxygen values obtained for each female subject, the criterion value, and the oxygen uptake values for those subjects who performed work beyond that required by the test.

The criterion designating maximal oxygen consumption for the females was identical to that used for the males, i.e., two successive readings differing by less than 0.080 litres.

For twenty-five oxygen consumption values recorded for the female subjects, twenty subjects actually reached values that could be classified as representative of their maximal capacity. The values for the remaining

TABLE XIII

HIGHEST, CRITERION, AND EXHAUSTION OXYGEN CONSUMPTION VALUES FOR FEMALES OBTAINED ON THE ASTRAND ACTUAL TEST

	Oxygen Consumption (litres/min)						
Subject	Highest	Criterion	Exhaustion	Subject	Highest	Criterion	Exhaustion
1	1.802	1.802		14	1.827	1.827	
2	1.883[a]			15	2.222[a]		
3	1.900	1.900		16	1.998	1.998	
4	2.381	2.381	1.714	17	--		
5	1.776	1.776	1.550	18	1.743	1.743	
6	2.241	2.241		19	1.762	1.762	
7	1.638	1.638		20	1.855	1.855	
8	1.725	1.725		21	1.690	1.690	
9	2.041	2.041		22	2.614	2.614	1.680
10	2.129[a]			23	1.577	1.577	
11	2.090	2.090		24	1.720[a]		
12	1.475	1.475		25	2.194	2.194	
13	2.186[a]			26	2.361	2.361	

[a]Continued to increase more than 0.080 litres throughout the test.

five subjects did not level off but continued to increase with increasing work load until the individual was no longer able to continue the test.

Only three subjects were able to respond to additional work beyond that required by the test. In all cases the oxygen consumption values continued to decrease from that value recorded as their maximal.

Discussion

The overall objective of this project was to establish, through the cooperation of several investigators, norms of work capacity for the secondary school population of Alberta. The test selected, which was considered one of the most proven and practical for such an extensive undertaking, was the Astrand test of work capacity in which the subject's

maximal oxygen intake was predicted from submaximal measurements of heart rate and work load. By limiting this study to one aspect of the total population, namely the secondary school students of Alberta, it was possible, not only to test a representative random sample of considerable magnitude, but to investigate, through the use of statistical procedures, differences in the predicted values of the subjects studied. Specifically, this study was designed to determine what differences, if any, existed in the work capacities of students living in cities as compared to those living on farms or in small towns.

Work Capacity: Urban—Rural Differences

The mean predicted value for the male urban group was 2.91 litres per minute as compared to 3.20 litres per minute for the rural group. The difference between these two means was found to be statistically significant at the .05 level of confidence. When these values were represented in millilitres per kilogram of body weight, 45.36 for the urban and 47.79 for the rural, a similar test of significance failed to reveal significant differences. As a result, the null hypothesis, which stated that no difference existed between these two values, was rejected only when the values were expressed in litres per minute.

When the data was subdivided into three age groups of 14-16 years inclusive, 17 years and 18-20 years inclusive, significant differences ($p = .05$) between the means of the male rural and urban groups expressed in litres per minute, were shown for both the 17 and 18-20 year groups. For these groups, the null hypothesis was rejected and the alternate hypothesis which stated that an actual difference did exist, was accepted.

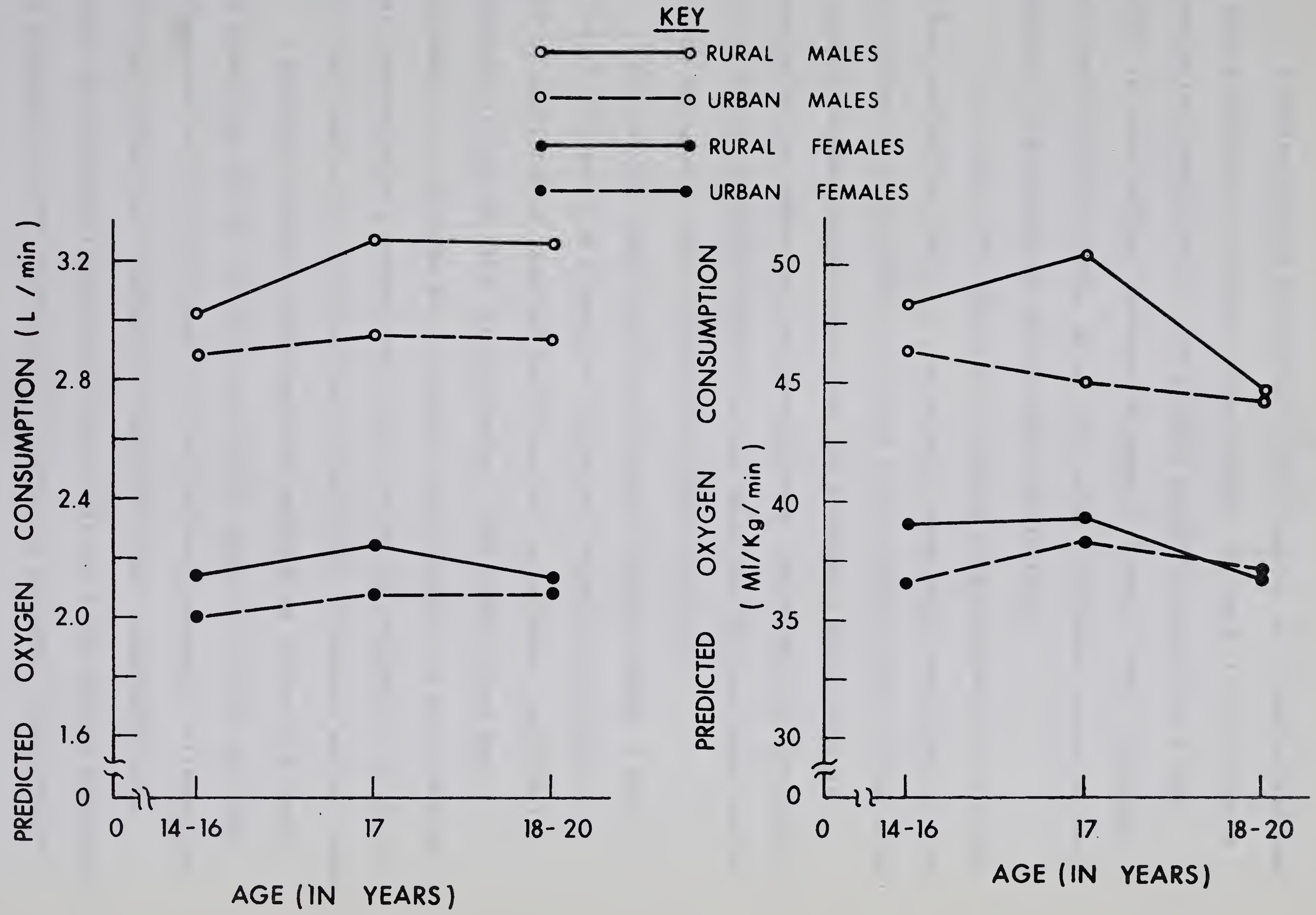
For the three groups, the urban means were 2.88, 2.95, and 2.94 as compared to the rural means of 3.02, 3.27, and 3.26 litres per minute.

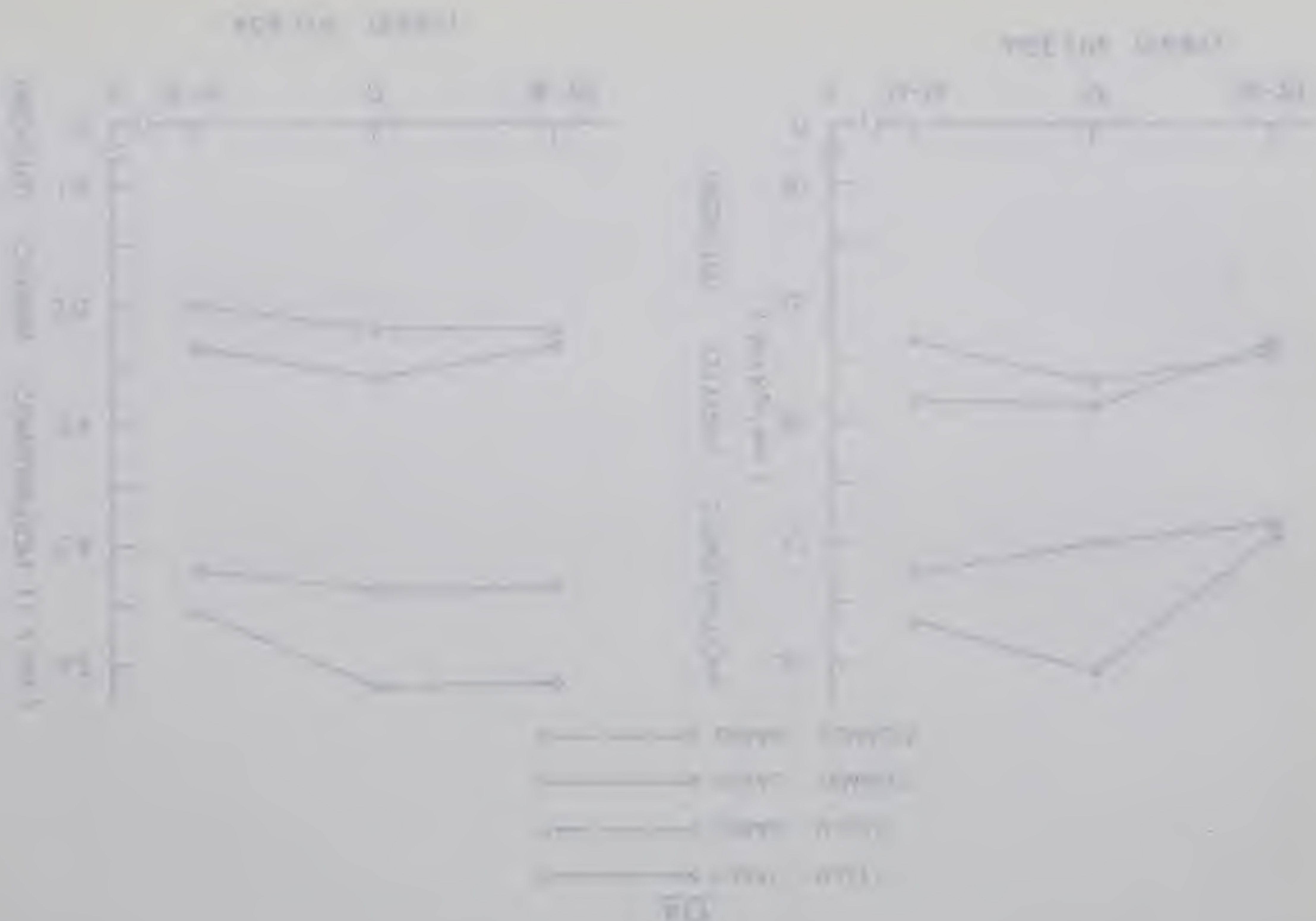
When body weight was considered, the urban means were 46.11, 45.01, and 44.37 millilitres per kilogram of body weight for the age groups 14-16, 17, and 18-20 years respectively. For the same age groups, the rural means were 48.23, 50.41, and 44.98. A statistically significant difference (p = .05) was shown only between the urban and rural 17 year old group.

In general, the rural male students showed a consistently greater predicted mean maximal oxygen intake value for each age group than did the urban students (figure III-viii). The random sampling techniques that were employed to collect the data indicated that actual differences did exist but statisticallly this was not confirmed because of the limited sample investigated.

The percentage differences, expressed in litres per minute, were: for the 14-16 age group, 4.94 per cent, for the 17 year group, 9.75 per cent and for the 18-20 age group, 9.77 per cent. When body weight was considered, the percentage differences became 4.39, 10.72, and 1.36 per cent respectively. When these percentage differences were compared with the percentage differences expressed in litres per minute, the rural-urban difference for the 18-20 age group was observed to decrease 8.41 per cent as a result of including the variable body weight. When the mean weight for this group was considered, the greater rural mean represented a difference of 7.60 per cent of the urban mean. The other two rural and urban groups showed little difference in their mean values for weight.

FIGURE III—viii PREDICTED OXYGEN CONSUMPTION MEAN VALUES FOR THE URBAN AND RURAL GROUPS





From the results presented, it would appear as if body weight has a direct influence on maximal oxygen uptake. Astrand (11) has found a correlation coefficient of 0.98 between oxygen consumption and body weight for male subjects between the ages of 4 and 33 years. Cumming and Cumming (32) and Adams, et al (2), using a different measure of work capacity, have also found similar high correlations.

If, in fact, the capacity for maximal oxygen uptake is a function of body weight then the only statistically meaningful conclusion that can be realized from this data is that the rural seventeen year old group had a greater maximal oxygen intake than the comparable urban group as measured by the submaximal test administered. No attempt has been made to explain why a significant difference was found for this age group and not for the age groups 14-16 inclusive and 18-20 inclusive.

For the 365 urban and 52 rural female students tested, a mean value of 2.03 and 2.16 litres per minute was found for each group. A test of significance revealed that these two values were significantly different at the .05 level of confidence. When these values were expressed in millilitres per kilogram of body weight, the rural females again demonstrated a greater mean value, 38.46, as compared to 37.15 for the urban sample, but a statistically significant difference was not found.

When the same age categories were employed as in the male sample, the urban mean values, in litres per minute, were 2.00, 2.08, and 2.08 as compared to 2.13, 2.24, and 2.13 for the rural students. Although the rural age groups had a higher mean value than their comparable urban groups, no statistical significance ($p = .05$) was shown for any comparison. The expression of the values in millilitres per kilogram of body weight

did not alter any conclusions regarding significance. The null hypothesis which stated that no difference existed between these mean values was not rejected in any case.

As was evidenced in the male groups, the female rural groups showed a consistently larger predicted oxygen consumption value (see figure III-viii). One exception was observed for the 18-20 year group where the rural mean value, expressed in millilitres per kilogram of body weight, was slightly less than the urban mean. The percentage differences between the three age groups were 6.33, 7.01, and 2.10 when litres per minute was the measure, and 6.28, 2.48, and -.52 when millilitres per kilogram of body weight was employed.

One of the difficulties in establishing a comparison between urban and rural areas using random sampling techniques is that it is difficult to obtain samples of a comparable size. Such was the case in this study. From a total of 917 students, 809 were from urban areas, and 108 from rural areas.

The basis for this investigation arose out of a widely-held belief that rural students are different in cardio-vascular fitness, as a result of their way of life, than those students attending city schools. In order to obtain a sample that would be representative of the rural-urban difference, it was necessary to define rural area as any agglomeration composed of less than 1,000 people. In this way the farm population was included in the sample.

As a consequence of this limitation the rural sample was considerably smaller than the urban sample. Statistically, this had important implications (45). The net effect was to cause a larger estimate of the

standard error of the mean than would have ordinarily been obtained if the samples had been equal. As a result, when the differences between the means were tested for significance, a lowered t value was obtained. This reduced the probability of finding a statistically significant difference between the rural and urban mean values.

No studies can be found in the literature which have investigated urban and rural differences using a similar submaximal test of work capacity. However, Adams, et al (1), using a submaximal test developed by Sjöstrand (77), investigated the physical working capacity of normal school children in the city and in the country of Sweden. For the age groups studied, 10, 11, and 12 years, it was found that the difference between the regression lines of both the country girls and boys and the city girls was significant (p = .01). These investigators also concluded that there was a significant difference between country and city girls (p = .02) and between Swedish country girls and California girls (p = .01). The fact that the subjects used in this study were not randomly selected prevents any inferences from being made of the parent population. The age groups investigated by Adams, et al (1) were considerably younger than those used in the present study.

The Relationship Between Heart Rate, Work Load and Oxygen Consumption

The structure of some of the basic submaximal tests for the determination of work capacity depends on a predictable relationship between certain cardiovascular parameters. In both the Sjöstrand (77) and the Astrand (16) test of work capacity, valid and reliable prediction of an individual's highest "steady state" or maximal capacity depends on the existence of a definite and reproducible linear relationship, within a certain range of values, for the parameters employed on these tests.

The Sjöstrand test is designed to predict an individual's work capacity, expressed in work rate, at a given heart rate of 170 beats per minute. The performance by a subject on two or three submaximal work loads, designed to elicit heart rates below this given value, permits extrapolation to the individual's capacity at 170 beats per minute, provided the individual has a rectilinear relationship between work load and heart rate within this range of values. Any deviation of these variables from linearity will necessarily result in a prediction not consistent with the construct of the test.

The Astrand test, on the other hand, purports to be able to predict an individual's maximal aerobic capacity from a single submaximal determination of heart rate at a given work load. Several conditions must be satisfied before an accurate prediction is possible. One prerequisite of the test is that the heart rate, and oxygen consumption for any given subject, are linearly related over a range of submaximal values (6).

In order to investigate the objectivity of these relationships, representatives of both sexes, and of the age classification of those used in the main study, were subjected to the Astrand actual test of work capacity (11) in which heart rate and oxygen consumption were measured at each work load that the subject performed at.

The data used for this investigation was limited to subjects who had performed at identical work loads. In the case of the male subjects, the total amount of work performed by each subject was equal, involving six minutes at each of the work levels, 600, 900, and 1,200 kilopond meters. Heart rates and oxygen consumption values were recorded during the last minute at each level.

For ten males who performed under these conditions, the correlation coefficients obtained between heart rate and work load, oxygen consumption and work load, and heart rate and oxygen consumption, were 0.94, 0.97, and 0.95 respectively. The range of heart rates for this data was 116 to 192 beats per minute.

For fourteen female subjects, all of whom pedalled at work loads of 300, 600, and 750 kilopond metres but the time pedalled on the final level was, in many instances, not the same, the relationship between oxygen consumption and work load yielded a correlation coefficient of 0.91.

The failure of the investigators, after repeated efforts, to obtain legible heart rate readings for the length of time required, prevented the investigation of other relationships. It must be emphasized that the correlation found between these variables was not limited to values obtained at known submaximal levels, but rather included heart rates and oxygen consumption values which could have been, especially in the case of the female subjects, their maximal values. These obtained correlation coefficients, therefore, must be considered large because it is recognized that at high values these variables tend to level off or assume an exponential function with increasing work load (71).

Taylor (79) has found correlation coefficients of 0.97 and 0.96 between work load and heart rate for two subjects in which twenty-four individual determinations were conducted on each of them. On three other subjects, the relationship between the same two variables yielded coefficients of 0.90, 0.69, and 0.94.

Bengtsson (21) investigated heart rate and work load for subjects under 14 years of age on a bicycle ergometer. He found that the

correlation coefficient between these two variables for both sexes was 0.94.

Many investigators (4,5,23,44,73) are of the general opinion that the relationship between heart rate, oxygen consumption and work load is rectilinear at submaximal levels--but there is considerable disagreement (11,33,73) as to what level these variables begin to show an exponential form.

Figure III-ix represents a typical pattern of heart rate and oxygen consumption with increasing work load found for a male subject.

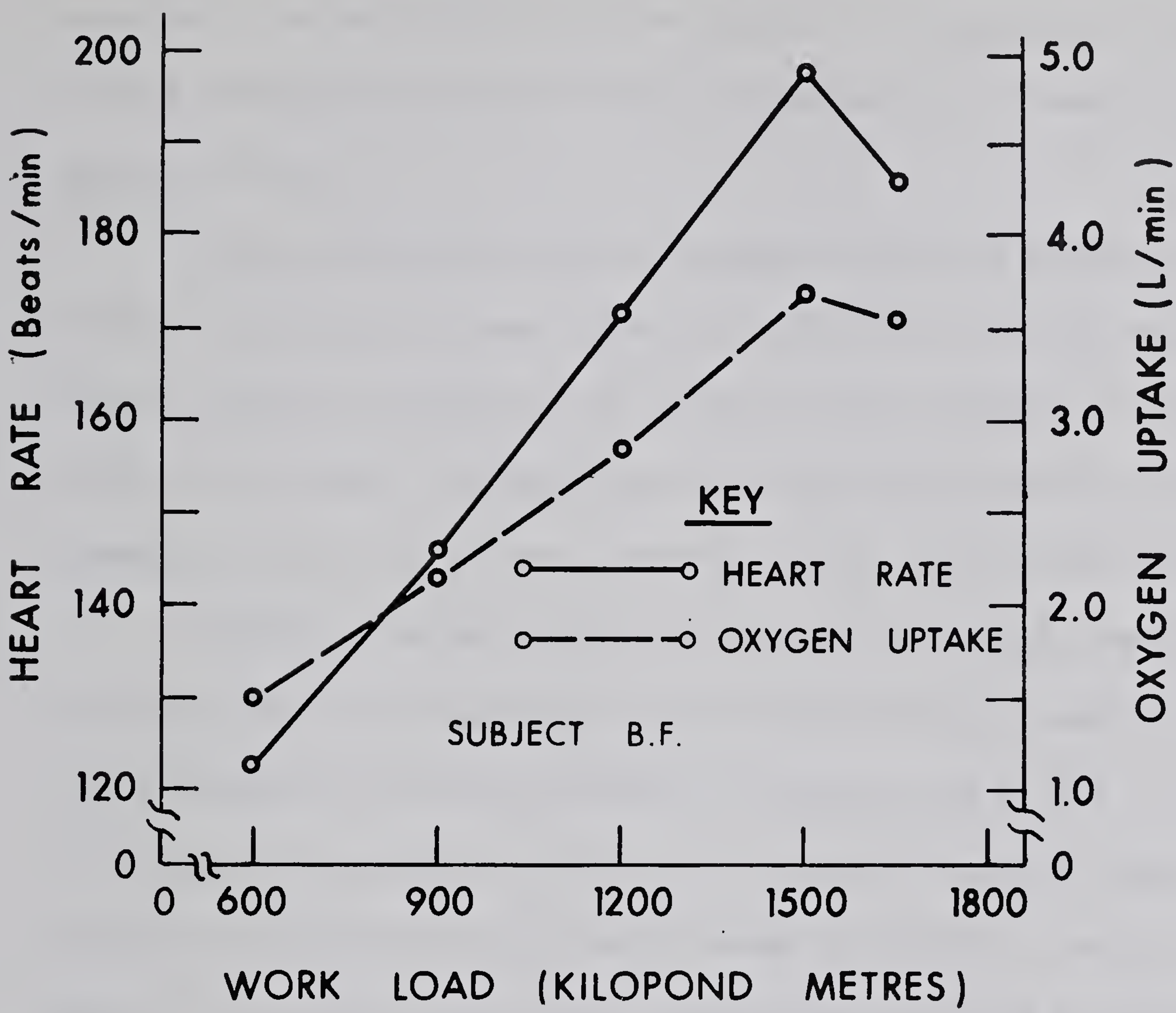
Figure III-x describes a pattern for oxygen consumption and work load for a female subject.

The fact that a high correlation was found in this study between these variables implies that there is a rough rectilinear relationship between them over the range of values investigated. It is possible, though, that at near maximal values, these measures changed to an exponential relationship, departing significantly from the linear trend. In both the Astrand and the Sjöstrand test, this assumption of linearity <u>must</u> be satisfied for heart rates over a certain range of values.

In an attempt to determine if a significant deviation from this linear relationship did exist over the range of values being investigated, trend analysis tests were carried out.

The results of these tests indicated that for the males, the trend of heart rate over increasing work load was almost completely linear in form. A test of significance revealed a highly significant linear component ($p = .005$) whereas no statistically significant deviation from linearity was observed. This meant that for the ten male subjects in

FIGURE III-ix A TYPICAL TREND OF HEART RATE AND OXYGEN CONSUMPTION OVER WORK LOAD FOR A MALE SUBJECT



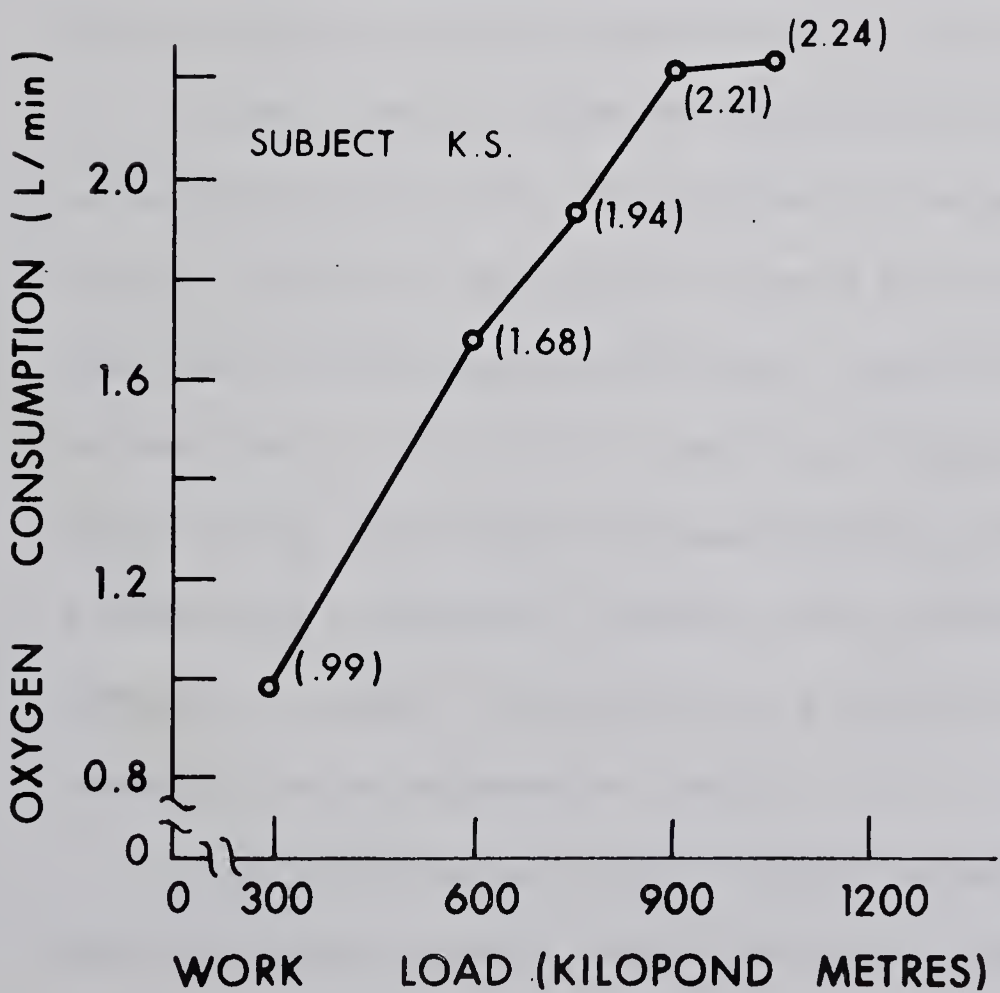


FIGURE III-x A TYPICAL TREND OF OXYGEN CONSUMPTION AND WORK LOAD FOR A FEMALE SUBJECT

question, the work rate that the subject could perform at could be accurately predicted from individual determinations of heart rates at submaximal levels.

The trend of the oxygen consumption values revealed a similar highly significant linear trend ($p = .005$), but for these values a significant quadratic component ($p = .05$) was also found to exist. In opposition to the purely linear heart rate trend, the oxygen consumption values tended to level off as their maximal values were approached.

The trend between oxygen consumption and work load for the females contained both a statistically significant linear component ($p = .005$) and a similar significant degree of curvature ($p = .005$). This quadratic trend was not surprising when it is realized that the trend for this parameter was analyzed over work loads of 300, 600, and 900 kilopond metres. The latter work level represented the load at which the majority of the subjects attained their maximal oxygen consumption value.

These findings revealed that when the heart rate and oxygen consumption values were plotted against the appropriate work load, the oxygen consumption values approached a horizontal asympote at a faster rate than did the heart rate values. For the functional relationship between heart rate and work load only a significant linear component was found whereas when oxygen consumption was plotted against work load both a linear and a quadratic component were revealed. It appeared that at low work rates, oxygen consumption has a linear function and at high work rates, it has an exponential form.

The relationship between oxygen consumption and heart rate depends upon the manner in which each of these parameters function over work load.

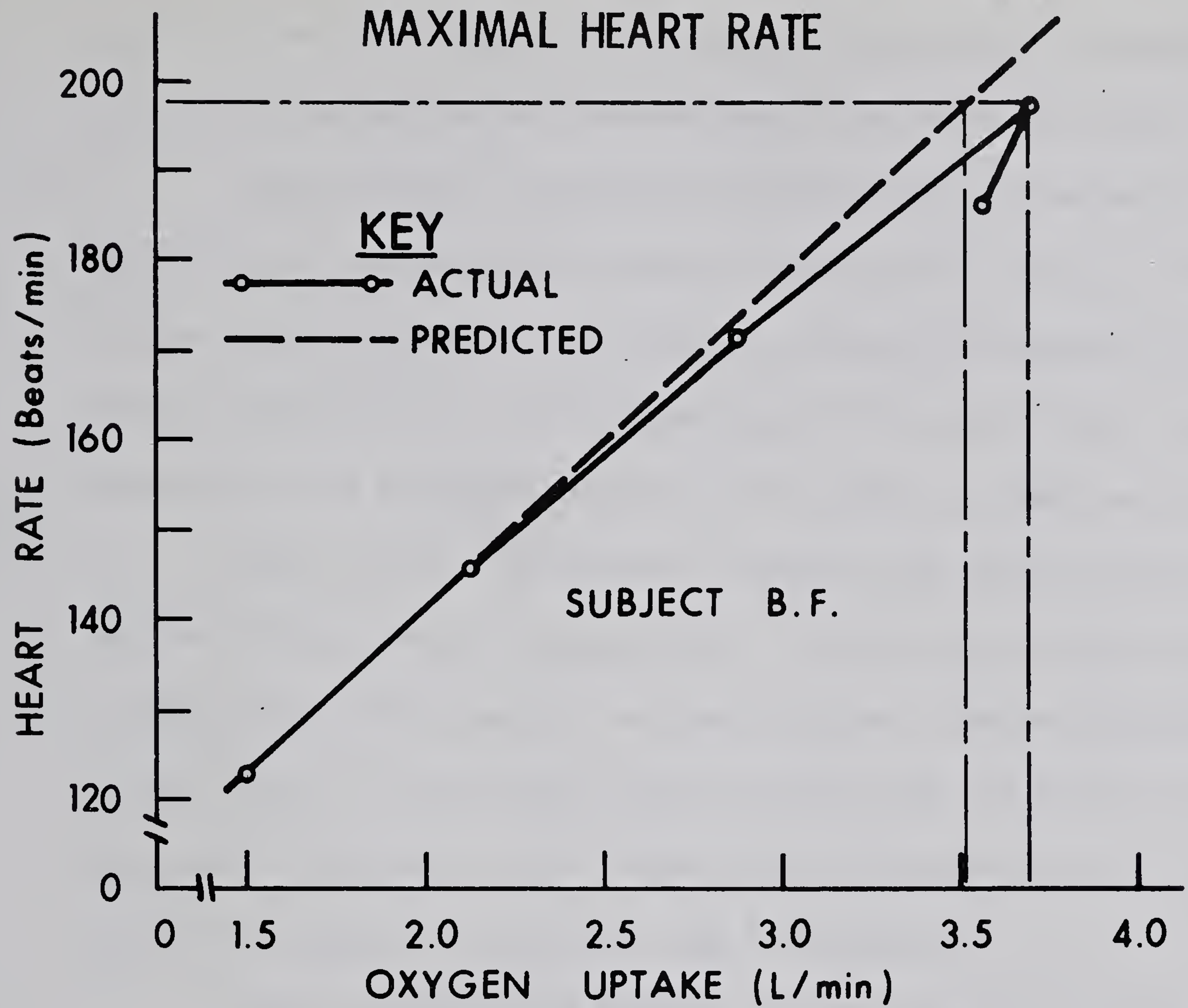
If both were only linearly related to work load, the it could be inferred that they would be only linearly related to each other. In recognition of the fact that this analysis revealed a significant quadratic component for the oxygen consumption-work load trend, it is expected that at high heart rates, the oxygen consumption-heart rate curve was exponential in form. As figure III-xi suggests, if prediction through linear extropolation is attempted, an underestimation of the individual's actual aerobic capacity would result.

These findings are consistent with those found by Wyndham, et al (90), in a study of maximal heart rates and maximal oxygen consumption measured during work performed on a bicycle ergometer. They found that the curve fitted to oxygen intake/work rate approached its asymptote more slowly than the curve fitted to heart rate/work rate. They concluded that when the heart rate is plotted against the oxygen intake, the linear relationship which held for most of the range of observations, deviated at high levels of work towards oxygen intake values higher than would be predicted from extrapolation of the linear part of the curve to the maximum heart rate values and reading of the appropriate oxygen intake values corresponding to the maximum heart rate.

On the basis of these findings, Wyndham, et al (90) rejected the Astrand submaximal test of work capacity as being incapable of accurately predicting maximal oxygen uptake.

Astrand (6), in response to this criticism, stated that it is not the premise of the nomogram that the heart rate is a rectilinear function of the oxygen uptake throughout the entire range of values. Rather, the nomogram, which enables this prediction to be made, was constructed empirically from data on heart rate and oxygen uptake during submaximal

FIGURE III-xi CURVE FITTED TO HEART RATE AND OXYGEN UPTAKE VALUES SHOWING DIFFERENCE BETWEEN ACTUAL AND PREDICTED OXYGEN UPTAKE AT MAXIMAL HEART RATE



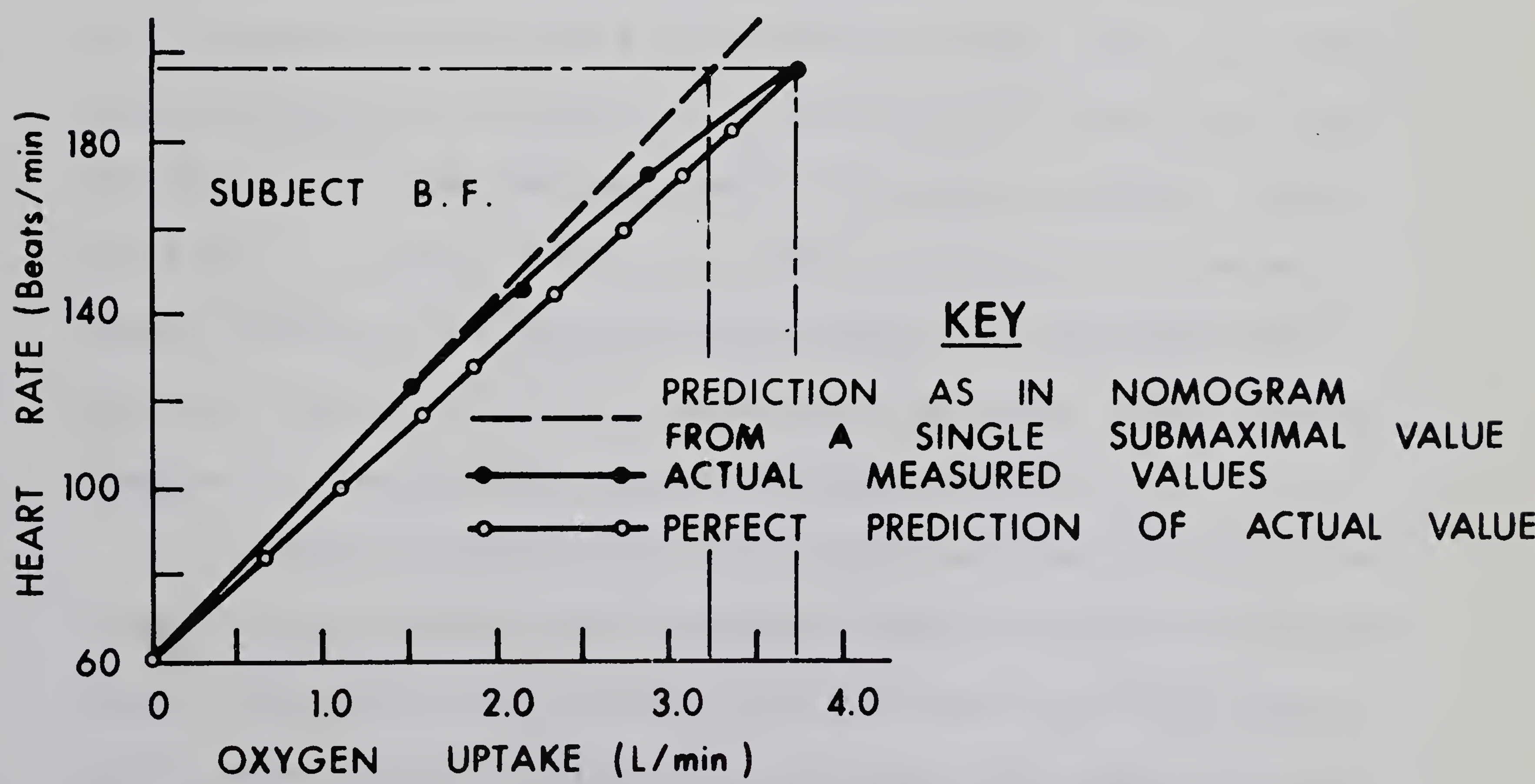


FIGURE III-xii CURVE FITTED TO A SINGLE SUBMAXIMAL VALUE OF HEART RATE AND OXYGEN UPTAKE SHOWING EXTERPOLATION TO A HEART RATE OF 195 BEATS PER MINUTE AS IN THE NOMOGRAM

work, and maximal oxygen uptake actually measured in experiments where the oxygen uptake values reached a well established level.

Figure III-xi illustrates the criticism presented by Wyndham, et al (90) from the data of a subject used in this study. If the individual's oxygen uptake value was predicted by linear extrapolation to his maximal heart rate value, an underestimation of his actual value would result because of the exponential form of the curve at high heart rates.

Figure III-xii graphically depicts the construction of the nomogram as described by Rowell, et al (72). "If the VO_2 to pulse rate slope is originated at 60 beats/min. and zero VO_2 and then extrapolated through a single value for submaximal VO_2 and pulse rate to a pulse rate of 195 beats/min., the VO_2 at the latter point corresponds exactly to that read from the nomogram as predicted VO_2." (72:925.)

These investigators further reported that the nomogram is based on the assumption that at work loads requiring 50 per cent of the maximal oxygen consumption, the heart rate will be close to 128 beats per minute and the maximal pulse rate approximately 195 beats per minute. Pulse rates which are below 128 beats per minute at 50 per cent of maximal oxygen consumption will overpredict the actual value and pulse rates above 128 beats per minute will underpredict the actual value. This is graphically illustrated for a subject in Figure III-xii.

If perfect prediction using the Astrand nomogram is to occur then it is necessary that the single submaximal measure of heart rate have an oxygen consumption directly proportional to 50 per cent of the individual's maximal capacity at 128 beats per minute. This means, in effect, that there must be a perfect linear relationship from a heart rate of 60

beats per minute and zero oxygen consumption through to the individual's maximal consumption at 195 beats per minute. If this is not so, and the relationship is curvilinear, as evidenced by the plotted values in Figure III-xii, then an inaccurate prediction will result. The greater the exponential form of the curve, the greater will be the discrepancy between measured and predicted values.

If, as Wyndham, et al (90), contended, and the results from the ten male subjects used in this study indicate, the heart rate-oxygen consumption curve has a horizontal asympote at high heart rates, then an accurate prediction will not result. The magnitude of error will be reflected by the degree to which the curve is not linear.

Although Astrand (6) has stated that the nomogram was compiled empirically from data of well conditioned subjects, 18-30 years of age, and that the linear relationship of heart rate over oxygen consumption was not investigated, it is suggested that the nomogram is based on this linear assumption for heart rates up to 195 beats per minute. It is only in this way that a heart rate of 128 beats per minute will elicit an oxygen consumption of 50 per cent of the maximal.

It is recommended that additional research be implemented to determine the form of the oxygen consumption-heart rate relationship on subjects of different ages and of different physical fitness levels. It is possible that if a consistent overprediction or underprediction of the actual value results for a specific type of subject, i.e., high and low fitness, an additional correction factor could be established to reduce the discrepancy between actual and predicted values.

Correlation Coefficients Obtained between Work Performed, Strength and The Actual and Predicted Maximal Oxygen Consumption Values

Glassford (49) and Baycroft (20), in an investigation of the Astrand submaximal test of work capacity (16), tested twenty-four healthy, physically active male subjects on three direct measures of maximal oxygen consumption and one submaximal predictive test. They found that of the three direct tests used, the Astrand actual test of work capacity yielded a significantly lower maximal oxygen uptake value. The mean maximal oxygen uptake value for the actual test was 3.485 litres per minute as compared to 3.714 for the Astrand submaximal test.

These investigators suggested that one possible reason for the lower measured maximal oxygen uptake value realized on the bicycle ergometer was due to the extreme fatigue of the leg muscles (notably the quadriceps), imposing, therefore, a strongly limiting factor on the ability of the individual to drive his cardiovascular-respiratory system to greater effort. It was recommended that further research be undertaken to ascertain the correlation between leg strength and maximal oxygen consumption.

One aspect of this study was designed to investigate the relationship of both the strength of the knee extensor muscles and work performed with the measured and the predicted maximal oxygen consumption values.

Significant correlation coefficients of 0.69 for the males and 0.68 for the females were found between the individual's measured maximal oxygen consumption values and the work performed in reaching this value. Both of these correlation coefficients were significant beyond the .01 level of confidence. The maximal oxygen measure in this case was the

maximal aerobic capacity recorded for the individual whether the value had declined or continued to increase with increasing work.

The relationship between these two variables was further investigated using only the data for those subjects who had actually reached a maximal oxygen consumption value as defined by the criterion of the test. This relationship changed only slightly for the males, yielding a lower coefficient (0.61) from that originally calculated, while an identical value (0.68) was observed for the females.

The magnitude of these correlation coefficients indicated that there was a significant relationship between the maximal oxygen consumption values obtained in this study and the work that was performed in attaining these values. This relationship was to be expected if, as Astrand (12) claims, the individual's capacity for heavy prolonged muscular work is limited by the supply of oxygen to the working muscles. The Astrand test of work capacity is based on the premise that the oxygen-transporting system is of fundamental importance to the ability to sustain heavy work.

The fact that insignificant changes were found in the correlation coefficients when only the criterion maximal oxygen values were used, indicated that there was little substance to the hypothesis that the difference between those who reached criterion value and those who did not was due to the amount of work performed.

When the average strength of the knee extensor muscles was correlated with the recorded maximal oxygen consumption value, correlation coefficients of 0.34 and 0.37 were obtained for the males and for the females respectively. Similar correlations were computed between this

measure of strength and the predicted maximal oxygen uptake value. These were 0.03 for the males and 0.46 for the females. Tests of significance revealed that none of these correlations were significantly different from zero.

Although a statistically significant relationship was not shown between these strength measures and the oxygen consumption values several comments seem necessary.

The strength values used in this study represented only an average measure of the isometric knee extensor strength of both legs as determined by the method outlined by Clarke (29). Considerable variation was shown by several subjects when the strength measures were obtained on each leg. Whether this was due to an inadequate recovery period between each trial or whether the submaximal test, performed before the strength tests, had some effect, was not determined. Several of the female subjects seemed incapable of exerting a maximal effort, an additional factor that could have contributed to the variation realized on these tests.

These strength measures, as previously mentioned, were isometrically determined. Performance on the bicycle ergometer is a dynamic activity, representing many more muscle groups and in different positions of application than those tested on the Clarke table (29). It is recommended that this relationship be further investigated using for the determination of strength, an activity which closely resembles the act of pedalling a bicycle.

The fact that the relationship between strength and predicted oxygen uptake was considerably greater for the females than for the males warrants further comment. The act of pedalling a bicycle ergometer

immobilizes, especially in submaximal work, the upper part of the body. Individual variations in body weight, therefore, assist little in the performance of a given work load. A statistically significant positive correlation between these two variables would have indicated that, to a degree, oxygen consumption varied directly with leg strength. Referred to the nomogram, this relationship could be interpreted in terms of the greater the leg strength of a subject the lower the heart rate used in the prediction of oxygen uptake. If the predicted value was, in fact, influenced by leg strength, then the capability of the submaximal test, for providing a prediction of an individual's aerobic capacity, must be seriously re-evaluated. The correlation coefficient of 0.46 found for sixteen female subjects between these two variables justifies the implementation of additional research.

Analysis of the Maximal Oxygen Consumption Values

Previous studies completed in Alberta (20,49), have mentioned that several of the subjects who performed the Astrand actual test of work capacity complained of severe fatigue of the leg extensor muscles at high work loads. It was suggested that for this reason the Astrand actual test gave a lower aerobic measure than either the Astrand predicted tests or the treadmill tests used in the study.

One of the subsidiary problems of this study was to investigate the effect of continued work on the oxygen consumption of a subject after his/her maximal values, as defined by the criteria of the Astrand test (6), had been reached.

For twenty-six male subjects tested on the Astrand actual test,

twenty-two reached a maximal oxygen consumption value which either declined or levelled off with additional work. Thirteen of these subjects were able to respond to an additional work load after the regular five-minute rest interval. The results showed that four of these subjects increased their maximal oxygen consumption values, one levelled off and the remaining eight continued to decrease. Of the four increases, only two were of sufficient value to indicate that the maximal oxygen consumption value had not been reached, i.e., increased beyond 0.080 litres per minute.

For twenty-five oxygen uptake values compiled for the female subjects, twenty were technically classified as representative of the individual's maximal aerobic capacity. Only three of these subjects felt that they had sufficiently recovered to attempt further work. In all three cases, the oxygen uptake values continued to decrease.

These results are in general agreement with those of Glassford (49) who found that for fourteen male subjects who participated at extra work levels not one developed a higher level of oxygen consumption.

From these results, it can be generally concluded that the criterion developed by Astrand (11), i.e., the values of two consecutive oxygen intake recordings differing by no more than $\pm$ 0.080 litres, was sufficient to indicate the maximal capacity, as measured by the bicycle ergometer, of the subjects used in this study.

Of considerable significance to the general acceptance of the Astrand actual test was whether or not the subjects were actually capable of attaining this criterion following the procedure suggested by the test. A closer inspection of the values revealed that seven male subjects did

not reach this plateau but continued to increase by increments greater than 0.080 litres throughout the test. Five of the female subjects demonstrated a similar tendency exhibiting progressive increases in oxygen consumption with increasing work load. The reason advanced by the majority of these subjects for the premature termination of the test was that their legs would not respond to the high work loads in question.

Wyndham, et al (90) have suggested several reasons to explain the slow approach of the oxygen uptake/work rate curve to its asymptote as found in their subjects. It might be that most of the subjects could not work themselves hard enough, to reach a maximal level of oxygen intake and/or at higher levels of work a greater number of muscles are brought into use and therefore the increase in oxygen consumption is not as great as when the lower extremity and trunk muscles are used at lower levels of work.

The subjects used in this study were representatives of the secondary school population of Alberta and as such several had no history of athletic participation. Whether or not these subjects would have been able to withstand a greater physiological stress on the treadmill or whether or not they would have again complained of excessive fatigure of the quadriceps muscles is a question left to be answered. It must be realized that the subjects used by Glassford (49) and Baycroft (20), the majority of whom reached maximal oxygen values as defined by the Astrand test, were healthy, physically active males in the age range of 17 to 33 years.

One thing seems evident from this discussion. If the Astrand actual test of work capacity is to be performed by a random representation

of the Canadian population, then modification of the test must be seriously considered. It is suggested that the work increments and/or the rest period between successive work periods be re-evaluated in terms of a population which has neither extensive athletic experience nor experience in riding a bicycle.

CHAPTER V

SUMMARY AND CONCLUSIONS

The main objective of this study was to investigate the working capacity of a representative random sample of the Alberta secondary school students. This sample was subdivided into rural and urban areas and tests of significance were carried out to determine what differences, if any, existed in their work capacities. An urban area was defined as an agglomeration of people in excess of 1,000. The rural group included the remaining locations found in the sample.

In all, a total of 809 urban and 108 rural subjects were tested on the Astrand submaximal test of working capacity.

Essentially, the test consisted of riding a bicycle ergometer for six minutes at a submaximal level. The determination of heart rate in a steady state and at a given work load enabled the individual's maximal oxygen consumption to be predicted from a nomogram. These values were expressed in litres per minute and in millilitres per kilogram of body weight.

A second objective of this study was to investigate certain variables related to the validation of the Astrand submaximal test. For this investigation, twenty-nine male and twenty-five female subjects, the majority of whom had been previously tested as part of the main problem, were selected to undergo a series of tests. The age of this sample ranged from 14 to 20 years.

Subjects reported to the laboratory twice and on each occasion

performed either the Astrand predicted test or the Astrand actual test of work capacity. The order of testing was randomly assigned for each subject. Data for height and weight was taken at the time of each test. The isometric knee extensor strength, determined by the Clarke tensiometer method, was taken after the submaximal test.

On the Astrand actual test, heart rate was recorded and expired air was collected during the last minute of each work load. The gas samples were analyzed on a Godart Capnograph carbon dioxide analyzer and a Beckman #E.2 oxygen analyzer.

In general, the rural groups demonstrated a consistently greater mean value for this measure of work capacity, whether expressed in litres per minute or in millilitres per kilogram of body weight, than did the comparable urban group. One exception was observed for the 18-20 year old female group where the rural mean value, expressed in millilitres per kilogram of body weight, was slightly less than the urban mean.

Several conclusions, supported by statistical procedures, were drawn from the results of this study.

1. The difference between the mean predicted values of oxygen consumption, expressed in litres per minute, for the male rural and urban students was found to be statistically significant at the .05 level of confidence. A similar significance was found for the difference between the means for the female rural and urban groups.

2. When this data was subdivided into age groups of 14-16 years inclusive, 17 years and 18-20 years inclusive, statistically significant differences between the means of the male rural and urban groups, expressed in litres per minute, was shown for the 17 and 18-20 year groups.

3. When the mean values were expressed in millilitres per kilogram of body weight, a statistically significant difference was shown only for the male 17 year old group.

The results from the subsidiary problems revealed several significant findings:

1. Correlation coefficients of 0.94, 0.97, and 0.95 were obtained between heart rate and work load, oxygen consumption and work load and heart rate and oxygen consumption for ten male subjects. For fourteen female subjects the correlation between oxygen consumption and work load was 0.91.

2. When an analysis for trend was computed, the curve fitted to heart rate and work load for the male subjects showed only a significant linear trend. The trend of oxygen consumption plotted against work load for the males and females showed both a statistically significant linear and quadratic component.

3. Statistically significant correlation coefficients of 0.69 for the males and 0.68 for the females were found between the measured maximal oxygen consumption value and the work performed in attaining this value.

4. For the male subjects, the relationship between work performed and the average isometric knee extensor strength yielded a statistically significant correlation of 0.51.

5. The correlations computed between strength and measured maximal oxygen consumption and strength and the predicted maximal oxygen consumption lacked statistical significance for both sexes.

6. For thirteen male and three female subjects who were able to respond to additional work after their oxygen consumption values had levelled off or declined, two subjects demonstrated a substantial increase in their values. It was concluded that the criterion developed by Astrand to indicate maximal aerobic capacity on the bicycle ergometer was sufficient for practical purposes.

7. The oxygen consumption values for seven male and five female subjects continued to increase throughout the test and did not display a tendency to level off before the subject was exhausted.

Recommendations

The results of this study indicated that additional research should be undertaken in several areas:

1. This investigation has provided a basis from which future extensive studies of work capacity can originate. Representative samples of all aspects of the total population should be tested with the ultimate aim of establishing norms on this parameter.

2. More research is needed to determine the effect of different conditions such as residence, occupation and socio-economic status on this measure of work capacity.

3. Future research should be directed towards the assumptions on which the Astrand submaximal test depends. Specifically, the linear relationship between heart rate, work load and oxygen consumption should be investigated on all age groups.

4. The influence of leg strength on both the Astrand actual test and the Astrand predicted test should be further researched. It is

recommended that the strength measures be relative to the activity in question.

5. It is suggested that the Astrand actual test be critically re-evaluated in terms of possible modification to the work increments and/or the rest period between successive work loads.

6. Maximal oxygen consumption values obtained on the bicycle ergometer should be compared with the values obtained on other forms of work, e.g., the treadmill and the step test.

8. The influence of emotion, of the degree of physical condition, of temperature and of food consumption on "predictive" submaximal tests should be determined.

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APPENDIX

APPENDIX A

STATISTICAL TREATMENT

Main Problem.

Computation of the Mean

$$\bar{X} = \frac{\sum X}{N} \qquad (45:37)$$

where: $\bar{X}$ = Mean

N = No. of observations

X = Value of observation

Computation of Variance and Standard Deviation.

$$S^2 = \frac{\sum X^2 - \frac{(\sum X)^2}{N}}{N - 1} \qquad (45:56)$$

$$S = \sqrt{S^2}$$

where: S^2 = variance

N = No. of observations

X = Value of observation

S = Standard deviation

Significance of the Difference Between Two Means.

$$T = \frac{\bar{X}_1 - \bar{X}_2}{S_{\bar{X}_1 - \bar{X}_2}} \qquad (43:94)$$

with $N_1 + N_2 - 2$ d.f.

Subsidiary Problems.

Computation of the Correlation Coefficient.

$$r = \frac{N\sum XY - \sum X \sum Y}{\sqrt{N \sum X^2 - (\sum X)^2 \quad N\sum Y^2 - (\sum Y)^2}} \qquad (45:92)$$

where: r = Correlation coefficient

X = Observation of Sample X

Y = Observation of Sample Y

Significance of the Correlation Coefficient.

$$T = r\sqrt{\frac{N - 2}{1 - r^2}} \qquad (45:52)$$

with $N - 2$ d.f.

where: r = correlation coefficient.

Analysis For Trend. A trend analysis was used to determine the trend of a series of means in which more than one observation or measurement was made on each subject (43:225).

A. Heart Rate and Work Load - Males.

Sum of Squares

1. Correction. $\frac{(\sum X)^2}{N} = \frac{(4711)^2}{30} = 739{,}784.03$

2. Total Sum of Squares around the general mean.

$$SS_T = (123)^2 + 124^2 + ---- + 190^2) - 739{,}784.03$$

$$= 758{,}225 - 739{,}784.03 = 18{,}440.97$$

3. Sum of squares between means of work loads.

$$SS_{trials} = \frac{(1278)^2}{10} + \frac{(1584)^2}{10} + \frac{(1849)^2}{10} - 739{,}784.03$$

$$= 756{,}114.1 - 739{,}784.03 = 16{,}330.07.$$

4. Sum of Squares among the Means of subjects.

$$SS_{subjects} = \frac{(441)^2 + (472)^2 + --- + (469)^2}{3} - 739{,}784.03$$

$$= 741{,}330.33 - 739{,}784.03 = 1{,}546.30$$

5. Interaction sum of squares.

$$\text{Interaction SS} = SS_T - (SS_{subjects} + SS_{Trials})$$

$$= 18{,}440.97 - (16{,}330.07 + 1{,}546.30)$$

$$= 546.60$$

6. Sum of Squares for trials = $SS_{linear} + SS_{curvature}$

$$SS_{Linear} = \frac{(-1)(1278) + 0(1584) + (1)(1849)}{(10)(2)} =$$

$$= \frac{326{,}041}{20} = 16{,}302.05$$

$$SS_{curvature} = SS_{Trials} - SS_{linear}$$

$$= 16{,}330.07 - 16{,}302.05 = 28.02.$$

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Linear Component	16,302.05	1	16,302.05	519.67
Curvature Component	28.02	1	28.02	.89
Among Subjects	1,546.30	(R-1) 9	171.81	<1
Interaction	564.60	(R-1)(C-1)=(2)(9)=18		
TOTAL	18,440.97	29		

B. Oxygen Consumption and Work Load - Males

Sum of Squares

1. Correction. $\frac{(\sum X)^2}{N} = \frac{(70.80)^2}{30} = 167.0880.$

2. Total Sum of Squares around the General Mean.

$$SS_T = (1.50^2 + 1.77^2 + ---- + 3.19^2) - 167.0880$$

$$= 180.0056 - 167.0880 = 12.9176$$

3. Sum of Squares Between Means of Work Loads

$$SS_{Trials} = \frac{(16.18^2)}{10} + \frac{(22.82)^2}{10} + \frac{(31.80)^2}{10} - 167.0880$$

$$= 179.3785 - 167.0880 = 12.2905$$

4. Sum of Squares Among the Means of Subjects.

$$SS_{Subjects} = \frac{(6.49)^2}{3} + \frac{(7.28)^2}{3} + \text{----} + \frac{(7.20)^2}{3} - 167.0880$$

$$= 167.4874 - 167.0880 = 0.3994$$

5. Interaction Sum of Squares.

$$\text{Interaction SS} = SS_T - (SS_{subjects} + SS_{trials})$$

$$= 12.9176 - (12.2905 + .3994) =$$

$$= 0.2277$$

6. Sum of Squares for Trials $= SS_{linear} + SS_{curvature}$

$$SS_{linear} = \frac{(-1)\ 16.18 + 0(22.82) + (1)(31.80)}{(10)(2)}^{2} =$$

$$= \frac{243.9844}{20} = 12.1992$$

$$SS_{Curvature} = SS_{trials} - SS_{linear}$$

$$= 12.2905 - 12.1992 = 0.0913$$

<u>Analysis of Variance</u>

Source of Variation	Sum of Squares	Degrees	Mean Square	F
Linear Component	12.1992	1	12.1992	960.57
Curvature Component	0.0913	1	0.0913	7.19
Among Subjects	0.3994	9		
Interaction	0.2277	18	.0127	
Total	72.9176	29		

C. <u>Oxygen Consumption And Work Load</u> - Females

Sum of Squares.

1. Correction. $\frac{(\sum X)^2}{N} = \frac{(63.48)^2}{42} = 95.9455$

2. Total sum of Squares Around the General Mean.

$$SS_T = (0.86)^2 + (0.75)^2 + ---- + (2.36)^2 - 95.9455$$
$$= 104.4542 - 95.9455 = 8.5087$$

3. Sum of Squares Between Means of Work Loads.

$$SS_{Trials} = \frac{(13.48)^2}{14} + \frac{(23.10)^2}{14} + \frac{(26.90)^2}{14} - 95.9455$$
$$= 102.7807 - 95.9455 - 6.8352$$

4. Sum of Squares Among the Means of Subjects.

$$SS_{Subjects} = \frac{(4.22)^2}{3} + \frac{(4.25)^2}{3} + ---- + \frac{(5.08)^2}{3} - 95.9455$$
$$= 96.7407 - 95.9455 = 0.7952$$

5. Interaction Sum of Squares

$$\text{Interaction SS} = SS_T - (SS_{subjects} + SS_{trials})$$
$$= 8.5087 - (6.8352 + 0.7952)$$
$$= 0.8783$$

6. Sum of Squares For Trials - $SS_{linear} + SS_{curvature}$.

$$SS_{Linear} = \frac{(1)(13.48) + 0(23.10) + (1)(26.90)}{(14)(2)}^{2} =$$
$$= \frac{180.0964}{28} = 6.4320$$
$$SS_{Curvature} = SS_{Trials} - SS_{Linear}$$
$$= 6.8352 - 6.4320 = 0.4032$$

Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Linear Component	6.4320	1	6.4320	190.30
Quadratic Component	0.4032	1	0.4032	11.93
Among Subjects	0.7952	13	0.0612	
Interaction	0.8783	26	0.0338	
Total	8.5087	41		

APPENDIX B

INDIVIDUAL SCORE SHEETS

Name: ________________ Date of Birth: ____________ Height: ______ in. Sex: _____

Previously tested at ________________________ High School

Submaximal VIO_2 Test	Maximal VIO_2 Test	Remarks:
Date ____________ Weight _______ lbs. _______ kgm. Resting Pulse Rate ______ b/min.	Date ____________ Weight _____ lbs. _____ Kgm. Resting Pulse Rate _________ b/min.	

Time (Min)	Heart Rate: Palpation, Time (sec)	Heart Rate: Palpation, H.R. b/min.	Heart Rate: ECG, b/min	Work Load (Kp.m)
1				
2				
3				
4				
5				
6				
7				
8				
Steady state				

Predicted VIO_2 ________ l.

________ ml./Kgm

Work Load Kpm	HEART RATES												ANALYSIS				DUPLICATE		
	PALPATION						ECG												
	1	2	3	4	5	6	1	2	3	4	5	6	CO_2	O_2	Vol.	VIO_2	CO_2	O_2	VIO_2

Actual VIO_2 ________ l.

________ ml./kgm

Steady State: Heart Rate _______ b/min.

Work Load _______ kp.m.

Predicted VIO_2 from Maximal Test: _______ l.

_______ ml./kg

ASTRAND BICYCLE ERGOMETER TEST

DATE OF TEST ____________________

NAME ______________________________ SEX ______ DATE OF BIRTH ________

ADDRESS ______________________________ HT. ___ WT. ________

SCHOOL ______________________________ GRADE ____________

RESIDENCE - Urban (Over 5,000) ____________

Rural (Under 1,000) - ____________ (1000-5000) ____ (Farm) _

SMOKE: Yes _____ No _____

Do you ride a Bicycle? Yes ____ No ____ Would you be tested again?
Yes ____ No _____

Gr. 12 Do you plan to attend U. of A. in Sept. 1964? Yes ____ No _____

Do you participate in the regular P.E. Program? Yes ____ No _____

DATA

TIME minutes	TIME 30 Bts.	TABLE Bts/min	WORK Load

Resting Pulse ______ Steady State Pulse ______ Pred. Max. O_2 __________

REMARKS:

Name ____________________

Date ____________________

t = __________ ^{o}C

B. P. = __________ mm. Hg

Factor = __________

FeO_2 = __________ x $\frac{2.5}{1000}$ = __________ F_IO_2 = 20.94

FeO_2 (corr.) = __________ F_ICO_2 = 00.03

$FeCO_2$ = __________ F_IN_2 = 79.03

FeN_2 = __________

V_EATPS = __________ l./min.

V_ESTPD = __________ x __________ = __________ l./min

V_ISTPD = __________ x __________ = __________

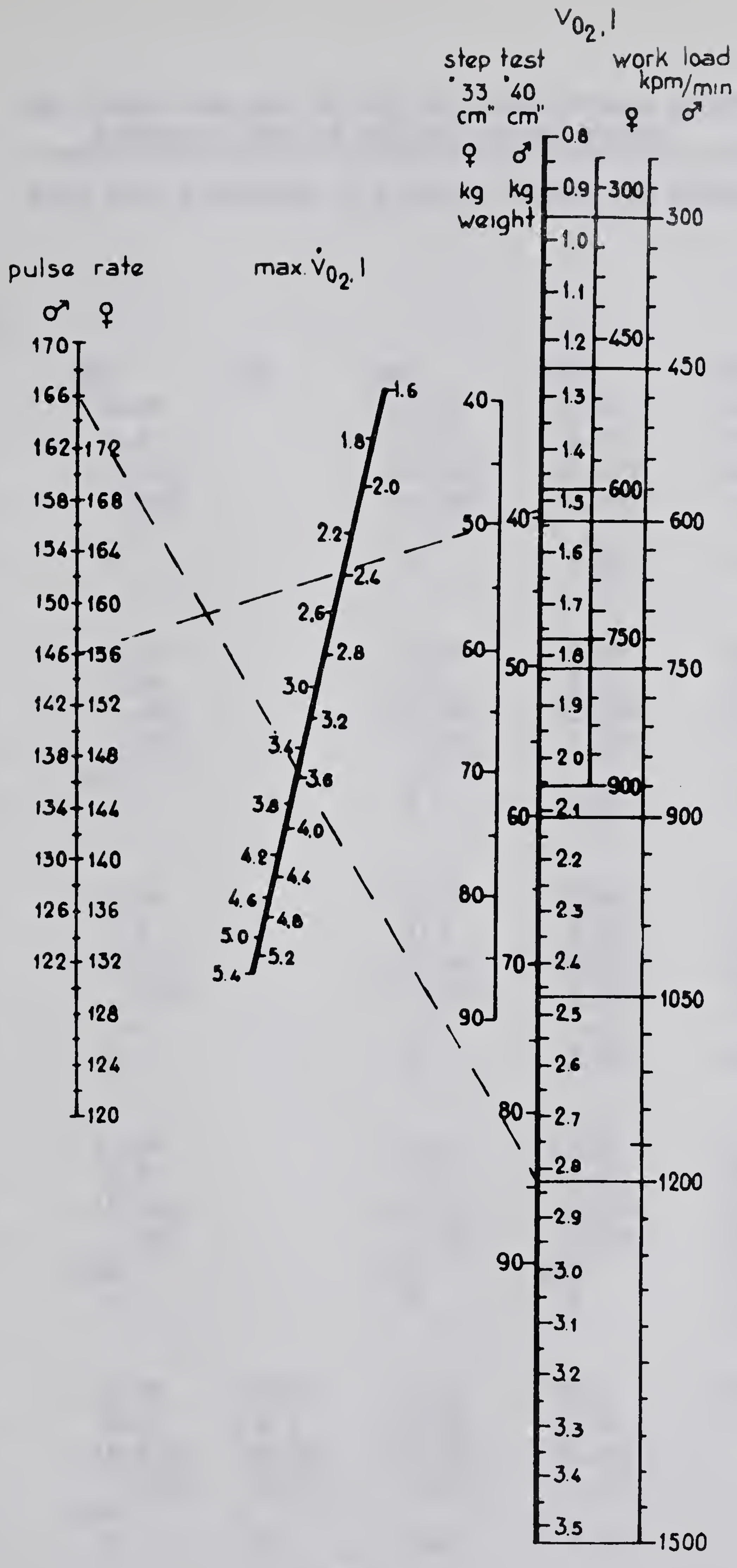
VO_2 = (__________ x 2094) - (__________ x __________) = __________ l./min

VCO_2 = (__________ x ______) - (__________ x .003) = __________ l./min

R. Q.= ____________________

APPENDIX C

RAW SCORES



The Åstrand nomogram for the calculation of aerobic work capacity from submaximal pulse rates and O_2-uptake values. (*From I. Åstrand, Acta Physiol. Scand., Suppl.* **49,** 169, 1960. *Reproduced by permission of the publisher.*)

RAW SCORES OBTAINED ON THE MODIFIED ASTRAND BICYCLE ERGOMETER TEST OF MAXIMAL OXYGEN UPTAKE.

WORK LOAD EXPRESSED IN KILOPOND METRES PER MINUTE

FEMALES.

	Subject						
1.	LB	300	450	600	750	700	1050
	$\%O_2$	16.06		17.09	17.05	16.94	
	$\%CO_2$	4.3		4.15	4.1	3.9	
	V_eSTPD	19.687		41.229	45.107	44.670	
	VO_2	.858		1.558	1.773	1.802	
	H.Rate	-		-	-	-	
	Time	6		6	2:56	1:30	
2.	M.M.						
	$\%O_2$	15.65		17.46	17.95	17.84	
	$\%CO_2$	5.0		3.9	3.3	2.95	
	VeSTPD	13.987		48.086	61.766	59.837	
	VO_2	.752		1.624	1.801	1.883	
	H.Rate	142		-	-	-	
	Time	6		6	2:30	1:19	
3.	J.M.						
	$\%O_2$	17.20		17.65	17.98	17.69	
	$\%CO_2$	3.9		3.5	3.25	3.1	
	V_eSTPD	26.323		52.946	64.202	57.602	
	VO_2	.975		1.717	1.856	1.900	
	H.R.	-		-	-	-	
	Time	6		6	3:29	1:35	
4.	B.O.						
	$\%O_2$	15.99		16.61	17.23	17.38	17.78
	$\%CO_2$	4.8		4.45	3.25	3.4	3.35
	V_eSTPD	19.560		46.142	62.008	55.714	54.964
	VO_2	.977		1.987	2.381	2.011	1.714
	H.R.	142		191	200	-	-
	Time	6		6	6	2:12	1:44
5.	L.W.						
	$\%O_2$	16.53	18.09	18.09	18.27	18.03	
	$\%CO_2$	3.8	2.9	2.85	2.6		
	V_eSTPD	19.973	62.427	53.894	51.667		
	VO_2	.915	1.776	1.418	1.550		
	H.R.	169					
	Time	6	6	2:41	1:12		

Females

Subject	300	450	600	750	900	1050
6. K.S.						
$\%O_2$	15.96		16.48	17.06	16.95	17.04
$\%CO_2$	4.4		4.55	4.1	4.2	4.2
V_eSTPD	19.284		37.089	50.523	56.157	58.527
VO_2	.992		1.684	1.935	2.214	2.241
H.R.	144		190	-	-	-
Time	6		6	6	3:14	2:2
7. M.P.						
$\%O_2$	17.58		18.32	18.18		
$\%CO_2$	3.2		2.7	2.4		
V_eSTPD	26.383		62.853	56.452		
VO_2	.903		1.638	1.616		
H.R.	-		-	-		
Time	6		5:30	1:30		
8. H.E.						
$\%O_2$	16.68		17.70	17.90	17.88	
$\%CO_2$	4.25		3.6	3.3	3.0	
V_eSTPD	19.020		49.097	57.909	51.366	
VO_2	.812		1.548	1.725	1.584	
H.R.	-		-	-	-	
Time	6		6	2:05	1:40	
9. S.Mc.						
$\%O_2$	16.87	16.69	17.24	17.20	17.27	
$\%CO_2$	3.6	3.95	3.5	3.45	3.35	
V_eSTPD	26.004	30.857	44.667	53.060	54.232	
VO_2	1.093	1.338	1.680	2.029	2.041	
H.R.	-	-	-	-	-	
Time	6	6	6	4:12	2:0	
10. A.B.						
$\%O_2$	16.98		17.07		17.97	
$\%CO_2$	3.5		3.9		3.35	
V_eSTPD	23.920		42.050		73.993	
VO_2	.978		1.627		2.129	
H.R.	-		-		-	
Time	6		6		3:45	

Females

Subject	300	450	600	750	900	1050
11. C.A.						
$\%O_2$		16.98	16.62	17.67	17.80	
$\%CO_2$		3.9	4.4	2.6	3.3	
V_eSTPD		30.021	35.334	60.483	66.825	
VO_2		1.196	1.522	2.090	2.075	
H.R.		159	191	-	-	
Time		6	6	4:46	1:50	
12. B.T.						
$\%O_2$	17.00		18.05	17.91		
$\%CO_2$	3.6		3.0	2.75		
V_eSTPD	22.310		47.451	45.387		
VO_2	.901		1.475	1.412		
H.R.						
Time	6		6	1:50		
13. H.M.						
$\%O_2$	16.55		16.49	17.49	17.45	
$\%CO_2$	4.1		4.4	3.7	3.2	
V_eSTPD	20.791		40.260	59.178	61.141	
VO_2	.931		1.800	2.007	2.186	
H.R.	146		191	-	-	
Time	6		6	3:49	1:48	
14. L.I.						
$\%O_2$	15.10		16.13	15.44	15.45	
$\%CO_2$	4.4		4.7	5.3	4.95	
V_eSTPD	22.937		39.911	32.853	30.424	
VO_2	1.197		1.547	1.827	1.716	
H.R.	-		-	-	-	
Time	6		6	6	3:14	
15. L.N.						
$\%O_2$	16.13		16.07	17.27	17.66	
$\%CO_2$	4.1		4.4	3.7	3.3	
V_eSTPD	17.399		30.128	55.827	67.698	
VO_2	.871		1.507	2.049	2.222	
H.R.	-		-	-	-	
Time	6		6	6	2:41	

Females

Subject	300	450	600	750	900	1050
16. L.W.						
%O_2	16.83		17.76	18.08	17.89	
%CO_2	3.9		3.2	3.1	2.9	
V_eSTPD	20.695		50.054	71.254	57.748	
VO_2	.864		1.593	1.998	1.789	
H.R.	-		-	-	-	
Time	6		6	3:25	1:08	
17. CG.	No Maximal Test					
%O_2						
%CO_2						
V_eSTPD						
VO_2						
H.R.						
Time						
18. J.R.						
%O_2	17.13		17.56	17.41	17.43	
%CO_2	3.9		3.5	3.4	3.2	
V_eSTPD	18.756		47.722	48.792	46.359	
VO_2	.712		1.602	1.743	1.669	
H.R.	152		-	-	-	
Time	6		5:01	2:13	1:15	
19. M.E.						
%O_2	16.48		17.71	18.13	18.09	
%CO_2	4.45		3.75	3.15	2.7	
V_eSTPD	18.471		49.952	64.593	58.911	
VO_2	.826		1.548	1.762	1.707	
H.R.	-		-	-	-	
Time	6		6	1:48	0:54	
20. C.Mc.						
%O_2	16.15		16.74	17.58	18.07	
%CO_2	4.1		4.15	3.4	2.9	
V_eSTPD	33.923		39.795	53.731	64.650	
VO_2	1.690		1.680	1.804	1.855	
H.R.	133		178	188		
Time	6		6	3:18	1:40	

Females

Subject	300	450	600	750	900	1050
21. K.B.						
$\%O_2$	16.49		17.45	17.78		
$\%CO_2$	3.9		3.5	3.5		
V_eSTPD	19.927		46.243	54.917		
VO_2	.825		1.616	1.690		
H.R.	-		-	-		
Time	6		6	2:15		
22. L.A.						
$\%O_2$	16.78	16.89	17.22	17.78	17.91	
$\%CO_2$	3.8	3.75	3.4	3.3	2.65	
V_eSTPD	21.347	30.515	68.553	58.952	53.520	
VO_2	.910	1.263	2.614	1.846	1.680	
H.R.	-	-	-	-	-	
Time	6	6	6	4:22	1:36	
23. I.K.						
$\%O_2$	16.06	16.33	17.00	16.51		
$\%CO_2$	4.3	4.4	3.8	3.55		
V_eSTPD	18.505	26.841	39.580	31.460		
VO_2	.933	1.255	1.577	1.469		
H.R.	-	-	-	-		
Time	6	6	2:54	1: 32		
24. G.L.						
$\%O_2$	16.28		17.56			
$\%CO_2$	4.7		4.0			
V_eSTPD	19.114		53.369			
VO_2	.891		1.720			
H.R.	-		-			
Time	6		5:16			
25. G.O.						
$\%O_2$	16.46		16.54		17.58	17.50
$\%CO_2$	4.3		4.2		3.8	3.3
V_eSTPD	19.016		33.976		67.44	60.223
VO_2	.862		1.515		2.194	2.099
H.R.	-		-		-	-
Time	6		6		6	1:44
26. J.C.						
$\%O_2$	16.18		16.51	16.96	16.87	17.04
$\%CO_2$	4.2		4.2	4.0	3.6	3.3
V_eSTPD	20.830		37.805	48.267	56.167	53.880
VO_2	1.024		1.701	1.922	2.361	2.188
H.R.	145		178	193	179	-
Time	6		6	4:30	2:07	1:26

RAW SCORES OBTAINED ON THE MODIFIED ASTRAND BICYCLE ERGOMETER TEST OF MAXIMAL OXYGEN UPTAKE.

WORK LOAD EXPRESSED IN KILOPOND METRES PER MINUTE

MALES.

Subject	600	900	1050	1200	1350	1500	1650
1. B.F.							
%O_2	17.67	16.87		17.00		17.43	17.30
%CO_2	3.4	3.8		3.8		3.5	3.2
V_eSTPD	46.144	51.350		71.678		105.022	94.414
VO_2	1.497	2.131		2.856		3.697	3.554
H.R.	123	146		172		198	186
Time	6	6		6		6	2:0
2. S.A.							
%O_2	16.38	17.36		17.76	17.69		
%CO_2	4.4	3.6		3.5	3.5		
V_eSTPD	33.936	72.975		101.378	90.85		
VO_2	1.564	2.614		3.146	2.959		
H.R.	156	195		-	205		
Time	6	6		3:10	1:38		
3. L.E.							
%O_2	15.90	15.60		16.542		17.08	16.44
%CO_2	4.7	4.9		4.6		3.9	3.4
V_eSTPD	34.400	39.864		76.490		88.312	67.745
VO_2	1.768	2.178		3.331		3.407	3.251
H.R.	124	160		188		186	175
Time	6	6		6		2:09	1:0
4. J.M.							
%O_2	16.91	17.42	17.67	17.53			
%CO_2	4.5	3.5	3.3	3.1			
V_eSTPD	41.333	80.671	75.703	71.933			
VO_2	1.618	2.851	2.475	2.518			
H.R.	154	192	188	183			
Time	6	6	2:16	1:02			

5. W.L.	300	600	750	900	1050
%O_2	15.86	15.96	16.89	17.15	17.19
%CO_2	4.6	5.0	4.4	4.0	3.8
V_eSTPD	16.077	31.810	46.764	50.113	51.395
VO_2	.837	1.585	1.854	1.875	1.925
H.R.	119	175	190	187	181
Time	6	6	6	3:27	1:31

Males

Subject	600	900	1050	1200	1350	1500	1650
6. D.B.							
$\%O_2$	17.53	18.15	18.06	17.90			
$\%CO_2$	3.6	3.1	3.0	2.9			
V_eSTPD	44.889	83.677	79.358	76.141			
VO_2	1.512	2.273	2.266	2.349			
H.R.	171	197	190	190			
Time	6	6	2:30	1:30			
7. D.Br.							
$\%O_2$	16.05	16.38		16.33		17.43	
$\%CO_2$	5.0	4.95		5.05		4.1	
V_eSTPD	32.614	50.763		70.380		88.211	
VO_2	1.588	2.266		3.168		2.965	
H.R.	121	149		182		188	
Time	6	6		6		3:03	
8. T.F.							
$\%O_2$	16.64	15.950		17.256	15.92	16.77	
$\%CO_2$	4.05	4.7		3.7	5.15	3.8	
V_eSTPD	39.438	46.397		88.287	71.807	86.689	
VO_2	1.721	2.355		3.251	3.586	3.706	
H.R.	126	146		184	188		
Time	6	6		6	3:60	1:45	
9. S.L.							
$\%O_2$	15.86	15.84		16.46			
$\%CO_2$	4.6	4.8		4.6			
V_eSTPD	31.579	43.588		64.246			
VO_2	1.647	2.261		2.863			
H.R.	138	173		186			
Time	6	6		2:40			

10. L.F.	600	750	900	1050
$\%O_2$	16.93	17.44	17.66	17.68
$\%CO_2$	4.05	3.41	3.3	2.8
V_eSTPD	45.658	67.296	78.927	82.963
VO_2	1.830	2.378	2.564	2.806
H.R.	181	199	201	185
Time	6	6	3:30	1:30

Subject	600	900	1050	1200	1350	1500	1650
11. S.W.							
$\%O_2$	16.25	16.60		17.93	17.78	17.94	
$\%CO_2$	4.65	4.2		3.1	2.8	2.6	
V_eSTPD	39.142	64.937		111.038	100.746	102.390	
VO_2	1.605	2.848		3.325	3.341	3.188	
H.R.	160	197		210	204	204	
Time	6	6		4:33	2:15	1:21	

Males

Subject	600	900	1050	1200	1350	1500	1650
12. V.H.							
$\%O_2$	16.11	17.04		17.51	16.89		
$\%CO_2$	4.8	4.0		3.65	3.3		
V_eSTPD	35.290	70.585		85.430	66.996		
VO_2	1.710	2.740		2.887	2.845		
H.R.	148	187					
Time	6	6		2:12	2:845		
13. J.S.							
$\%O_2$	15.93	16.35		17.43	17.65		
$\%CO_2$	4.8	4.65		3.95	3.8		
V_eSTPD	31.717	49.066		84.628	89.740		
VO_2	1.609	2.248		2.879	2.838		
H.R.	127	157		178	175		
Time	6	6		6	2:04		
14. L.C.							
$\%O_2$	16.78	16.99		17.33		17.53	17.98
$\%CO_2$	4.4	4.2		3.8		3.3	2.6
V_eSTPD	41.774	65.826		99.226		103.891	110.021
VO_2	1.708	2.562		3.540		3.581	3.370
H.R.	145	178		192		191	176
Time	6	6		6		1:44	0:59
15. K.S.							
$\%O_2$	16.13	16.84		17.54	17.70	17.69	
$\%CO_2$	4.65	4.2		3.55	3.1	2.95	
V_eSTPD	30.373	54.786		86.031	87.613	84.818	
VO_2	1.478	2.236		2.898	2.878	2.831	
H.R.	152	188		185	194	186	
Time	6	6		4:30	2:43	1:35	
16. B.J.							
$\%O_2$	15.77	16.11		16.78	17.51	16.78	
$\%CO_2$	4.8	4.8		4.4	3.85	3.55	
V_eSTPD	29.446	47.112		76.600	96.539	74.201	
VO_2	1.554	2.283		3.144	3.211	3.213	
H.R.	138	160		186	183	-	
17. N.F.							
$\%O_2$	15.95	16.20	17.13	16.93	17.16		
$\%CO_2$	4.65	4.6	3.9	3.55	3.6		
V_eSTPD	38.287	50.823	14.629	68.574	79.961		
VO_2	1.948	2.432	2.832	2.839	3.067		
H.R.	141	180	198	189	191		
Time	6	6	6	1:43	2:02		

Males

Subject	600	900	1050	1200	1350	1500	1650
18. $\%O_2$	16.52	16.53	16.66	16.73	17.00		
$\%CO_2$	4.35	4.4	4.05	4.2	3.5		
V_eSTPD	40.108	59.144	69.222	78.770	86.206		
VO_2	1.783	2.615	3.010	3.325	3.504		
H.R.	139	179	191	192	183		
Time	6	6	6	3:23	2:30		
19. R.C.							
$\%O_2$	16.00	17.10	17.58	19.98			
$\%CO_2$	5.05	4.3	3.8	3.25			
V_eSTPD	29.144	60.520	76.388	69.196			
VO_2	1.433	2.255	2.484	2.438			
H.R.	166	204	204	201			
Time	6	6	2:15	1:14			
20. T.B.							
$\%O_2$	16.56	16.50		16.95	17.23	16.75	
$\%CO_2$	4.2	4.65		4.3	3.75	3.4	
V_eSTPD	37.706	54.408		78.190	82.703	61.744	
VO_2	1.672	2.390		3.062	3.066	2.721	
H.R.	135	167		182	178		
Time	6	6		5	1:50	0:46	
21. T.F.							
$\%O_2$	15.41	15.63		17.45			
$\%CO_2$	5.0	4.95		3.9			
V_eSTPD	26.648	37.897		96.160			
VO_2	1.513	2.051		3.259			
H.R.	122	153		185			
Time	6	6		6			
22. K.M.							
$\%O_2$	15.68	16.295	17.13	17.06	16.13		
$\%CO_2$	4.85	4.45	3.8	3.7	3.9		
V_eSTPD	32.727	56.249	83.229	77.645	55.249		
VO_2	1.760	2.862	3.180	3.046	2.795		
H.R.	132	174	191	180			
Time	6	6	6	2:30	1:10		
23. S.F.							
$\%O_2$	15.99	16.28	17.71	17.31			
$\%CO_2$	4.65	4.6	3.2	3.2			
V_eSTPD	34.572	55.919	106.736	88.754			
VO_2	1.750	2.619	3.465	3.330			
H.R.	151	188	209	200			
Time	6	6	6	1:52			

Males

Subject	300	600	900	1050	1200	1350	1500
24. R.B.							
$\%O_2$		15.90	15.85		16.96	17.29	17.10
$\%CO_2$		5.3	5.3		4.3	3.85	3.4
V_eSTPD		31.084	47.613		81.532	88.645	82.471
VO_2		1.548	2.401		3.182	3.184	3.269
H.R.		136	172		192	188	177
Time		6	6		6	2:40	1:06
25. P.P.							
$\%O_2$		16.87	17.59	18.07	18.12		
$\%CO_2$		4.2	3.35	2.8	2.6		
V_eSTPD		46.296	74.529	83.513	87.740		
VO_2		1.872	2.503	3.254	2.532		
H.R.		151	187	185	181		
Time		6	6	2:05	1:15		
26. B.B.		<u>600</u>	<u>750</u>	<u>900</u>			
$\%O_2$		16.54	16.75	17.11			
$\%CO_2$		4.4	4.3	4.15			
V_eSTPD		38.299	40.140				
VO_2		1.688	1.673				
H.R.		140	168	188			
Time		6	6	6			
27. G.M.							
$\%O_2$		16.46	17.90	17.85	18.07		
$\%CO_2$		4.35	3.2	2.95	2.5		
V_eSTPD		33.847	86.263	73.694	75.263		
VO_2		1.526	2.593	2.310	2.240		
H.R.		158	196	195	185		
Time		6	6	2:39	1:12		
28. K.C.							
$\%O_2$		16.03	16.21		16.96		
$\%CO_2$		5.0	5.0		4.45		
V_eSTPD		34.10	50.94		82.562		
VO_2		1.669	2.338		3.190		
H.R.		116	163		190		
Time		6	6		6		
29. J.K.							
$\%O_2$		15.68	15.88		17.27	17.42	
$\%CO_2$		4.7	4.7		3.65	2.8	
V_eSTPD		30.743	50.373		79.405	83.714	
VO_2		1.665	2.601		2.925	3.113	
HR		147	196				
Time		6	6		2:30	1:00	

Males

	Subject	300	600	900	1050	1200	1350
30.	RJ						
	$\%O_2$	17.04	16.95	18.27	18.34		
	$\%CO_2$	3.7	4.0	2.85	2.4		
	V_eSTPD	22.041	38.079	76.539	69.978		
	VO_2	.873	1.521	2.023	1.862		
	H.R.	170	187	200	191		
	Time	6	6	6	1:50		

MALES

No.	Strength Sum of Trials R.L.	L.L.	Average	Score	Maximal Oxygen Con. Predicted l/min	Actual l/min	Work Performed Kilopond Metre Minutes (÷100)
1	147	158	51	200	3.48	3.70	162.00[a]
2	133	118	42	167	2.34	3.15	38.04
3	160	151	52	204	2.72	3.41	104.25
4	--	--	--	--	--	2.85	--
5	--	--	--	--	2.00	1.93	15.75
6	--	--	--	--	2.23	2.35	44.25
7	--	--	--	--	3.52	3.17	72.00
8	171	186	59	230	3.58	3.71	152.25
9	113	129	40	160	--	2.86	32.04
10	118	125	40	160	--	2.81	--
11	177	151	55	216	2.56	3.34	60.98
12	149	130	47	185	--	2.89	26.40
13	159	155	52	204	3.06	2.88	72.00
14	157	186	56	220	2.86	3.58	97.95
15	89	72	27	125	2.99	2.90	55.44
16	162	135	50	197	2.43	3.21	132.45
17	194	180	62	240	2.76	3.07	111.05
18	--	--	--	--	--	3.50	137.31
19	195	180	62	240	2.06	2.48	23.63
20	120	143	44	174	2.76	3.07	84.71
21	109	134	41	163	3.74	3.26	72.00
22	123	136	43	170	3.04	3.18	63.00
23	--	--	--	--	--	3.47	63.00
24	185	190	62	240	3.21	3.27	132.00
25	140	117	43	170	2.33	3.25	21.84
26	135	122	43	170	2.76	--	--
27	111	120	39	157	2.32	2.59	27.83
28	--	--	--	--	4.05	3.20	72.00
29	171	167	56	220	--	3.11	--
30	127	134	43	170	--	2.02	43.50

[a]Represents the total work performed (kilopond metres x minutes) above 900 kilopond metres to level of actual maximal oxygen value.

RAW SCORES FOR SUBSIDIARY PROBLEM

FEMALES

No.	Strength Sum of Trials R.L.	L.L.	Average	Score	Maximal Oxygen Con. Predicted 1/min	Actual 1/min	Work Performed Kilopond Metre Minutes (÷100)
1	74	76	25	120	1.67[c]	1.80[b]	35.48[a]
2	70	68	23	113	1.91	1.88	30.63
3	115	109	37	153	--	1.90	40.32
4	113	118	39	157	1.76	2.38	45.00
5	--	--	--	--	--	1.78	--
6	147	120	45	177	--	2.24	95.39
7	87	81	28	128	--	1.62	--
8	65	97	27	125	--	1.73	8.10
9	61	65	21	108	--	2.04	--
10	107	96	34	145	1.79	2.13	33.75
11	120	129	42	167	--	2.09	--
12	70	49	20	105	--	1.48	--
13	113	115	38	155	1.94	2.19	44.85
14	129	127	43	170	--	1.83	45.00
15	166	136	50	197	--	2.22	69.12
16	166	168	56	220	--	2.00	25.65
17	--	--	--	--	1.44	--	--
18	--	--	--	--	1.61	1.74	--
19	74	78	25	120	1.61	1.76	13.50
20	100	99	33	142	2.13	1.86	39.78
21	114	111	38	155	1.54	1.69	16.88
22	67	77	24	117	1.79	2.61	--
23	93	101	32	140	1.58	1.58	--
24	87	106	32	140	1.68	--	--
25	117	118	39	157	1.99	2.19	45.00
26	131	149	47	185	2.51	2.36	52.83
27	171	176	58	227	1.71	--	--

[a] Represents the total work performed (kilopond meters x minutes), above 600 kilopond metres to level of actual maximal oxygen intake value.

[b] Represents the largest oxygen uptake value obtained on the actual test.

[c] Results of the predicted submaximal test corrected for age.

PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM PULSE RATE AND WORK LOAD ON A BICYCLE ERGOMETER

MALES

Working Pulse	Maximal Oxygen Uptake (l/min) kpm/min	Maximal Oxygen Uptake (l/min) kpm/min	Working Pulse	Maximal Oxygen Uptake (l/min) kpm/min	Maximal Oxygen Uptake (l/min) kpm/min
120	3.50[a]	4.80	146	2.40	3.30
121	3.45	4.70	147	2.38	3.28
122	3.40	4.62	148	2.35	3.24
123	3.35	4.60	149	2.33	3.20
124	3.30	4.54	150	2.30	3.15
125	3.20	4.43	151	2.28	3.12
126	3.18	4.35	152	2.25	3.08
127	3.14	4.30	153	2.22	3.64
128	3.10	4.20	154	2.20	3.00
129	3.04	4.15	155	2.18	2.98
130	3.00	4.10	156	2.15	2.94
131	2.94	4.14	157	2.13	2.90
132	2.90	4.00	158	2.11	2.88
133	2.84	3.94	159	2.10	2.84
134	2.80	3.90	160	2.08	2.82
135	2.78	3.84	161	2.04	2.80
136	2.74	3.78	162	2.02	2.78
137	2.70	3.70	163	2.00	2.75
138	2.68	3.65	164	1.99	2.70
139	2.65	3.60	165	1.98	2.68
140	2.62	3.55	166	1.94	2.65
141	2.60	3.52	167	1.92	2.62
142	2.54	3.48	168	1.90	2.60
143	2.51	3.42	169	1.88	2.58
144	2.50	3.39	170	1.84	2.55
145	2.44	3.35			

[a]The above values were read directly from the nomogram (16) as were values for work loads not listed. Each value was multiplied by the factor 1.1 (14). (The correction factor for age.)

PREDICTION OF MAXIMAL OXYGEN UPTAKE FROM PULSE RATE AND WORK LOAD ON A BICYCLE ERGOMETER

FEMALES

Maximal Oxygen Uptake (l/min)				Maximal Oxygen Uptake (l/min)			
Working Pulse	300 kpm/min	450 kpm/min	600 kpm/min	Working Pulse	300 kpm/min	450 kpm/min	600 kpm/min
120	2.58	3.35	4.10	146	1.63	2.15	2.64
121	2.50	3.30	4.00	147	1.61	2.13	2.62
122	2.50	3.20	3.90	148	16.0	2.10	2.58
123	2.40	3.15	3.85	149	1.55	2.07	2.55
124	2.40	3.10	3.80	150	1.53	2.04	2.50
125	2.34	3.04	3.70	151	1.50	2.00	2.48
126	2.30	2.98	3.60	152	1.50	1.98	2.45
127	2.24	2.90	3.54	153	1.46	1.95	2.40
128	2.20	2.85	3.52	154	1.45	1.93	2.38
129	2.15	2.78	3.44	155	1.42	1.92	2.35
130	2.10	2.75	3.40	156	1.40	1.90	2.32
131	2.07	2.70	3.35	157	1.38	1.87	2.30
132	2.03	2.67	3.25	158	1.35	1.85	2.27
133	2.00	2.63	3.20	159	1.34	1.82	2.24
134	2.00	2.60	3.18	160	1.31	1.80	2.22
135	1.95	2.55	3.12	161	1.30	1.78	2.20
136	1.92	2.50	3.05	162	1.28	1.75	2.18
137	1.90	2.45	3.00	163	1.25	1.72	2.15
138	1.84	2.40	2.97	164	1.23	1.71	2.12
139	1.81	2.38	2.92	165	1.21	1.70	2.10
140	1.80	2.34	2.84	166	1.20	1.68	2.08
141	1.77	2.30	2.80	167	1.17	1.65	2.05
142	1.75	2.28	2.78	168	1.16	1.63	2.03
143	1.72	2.25	2.75	169	1.15	1.61	2.00
144	1.70	2.20	2.72	170	1.13	1.60	1.99
145	1.64	2.18	2.70				

APPENDIX D

CORRECTION FACTORS

CORRECTIONS FOR AMERICAN METER CO. GAS METER #802

The meter was tested for its volume determinations using as standards the large Tissot tank in the Faculty of Physical Education Laboratory and a smaller Tissot in the Cardio-pulmonary Laboratory at the University Hospital. It was found to be recording volume readings in excess of actual volumes pumped, as indicated by the Tissot tanks. A second American Meter Co. gas meter, in use at the University Hospital, was found to give extremely accurate readings when compared to the same Tissot tanks.

The data collected was analyzed and a regression equation calculated. This equation was found to be -

$$Y = .22770 + .943099X$$

where Y = corrected volume

and X = volume as read on the American Meter Co. Gas Meter #802.

This regression equation was then used to calculate a complete set of correction tables. These tables also incorporate a factor for loss of volume during oxygen and carbon dioxide analysis, with the factor being considered as 300 c.c.

CORRECTIONS FOR THE BECKMAN E-2 OXYGEN ANALYZER

The accuracy of this instrument was tested against two micro-Scholander instruments operated by laboratory technicians in the Cardio-pulmonary Laboratory at the University of Alberta and laboratory of the Department of Physiology at the University of Alberta.

The values obtained with the two Scholanders were averaged and a regression equation based on the Beckman reading and Scholander values was calculated.

This equation was found to be:

$$Y^{1} = .893\ X\ 2.22$$

where Y^{1} = corrected percentage of oxygen

and X = percentage of oxygen as read on the Beckman E-2 analyzer.

The discrepancy was found to be due to impure nitrogen which was used as a calibration gas.

This correction factor was only needed to correct some of the oxygen values. In the latter part of the experiment a second cylinder of nitrogen, which was found to be pure when tested, was used as the calibration gas.

CORRECTION FOR PALPATION HEART RATES

Heart rates obtained by the palpation method were found to be in error when compared with 24-30 beat complexes obtained for the electrocardiograph.

Regression lines for each of the three investigators were constructed on the basis of the electrocardiograph values.

The equations were found to be:

Investigator	Regression Lines
H.G.	$Y = 1.067\,X - 4.42$
R.N.	$Y = 1.001\,X - 5.42$
R.H.	$Y = 1.036\,X - 2.71$